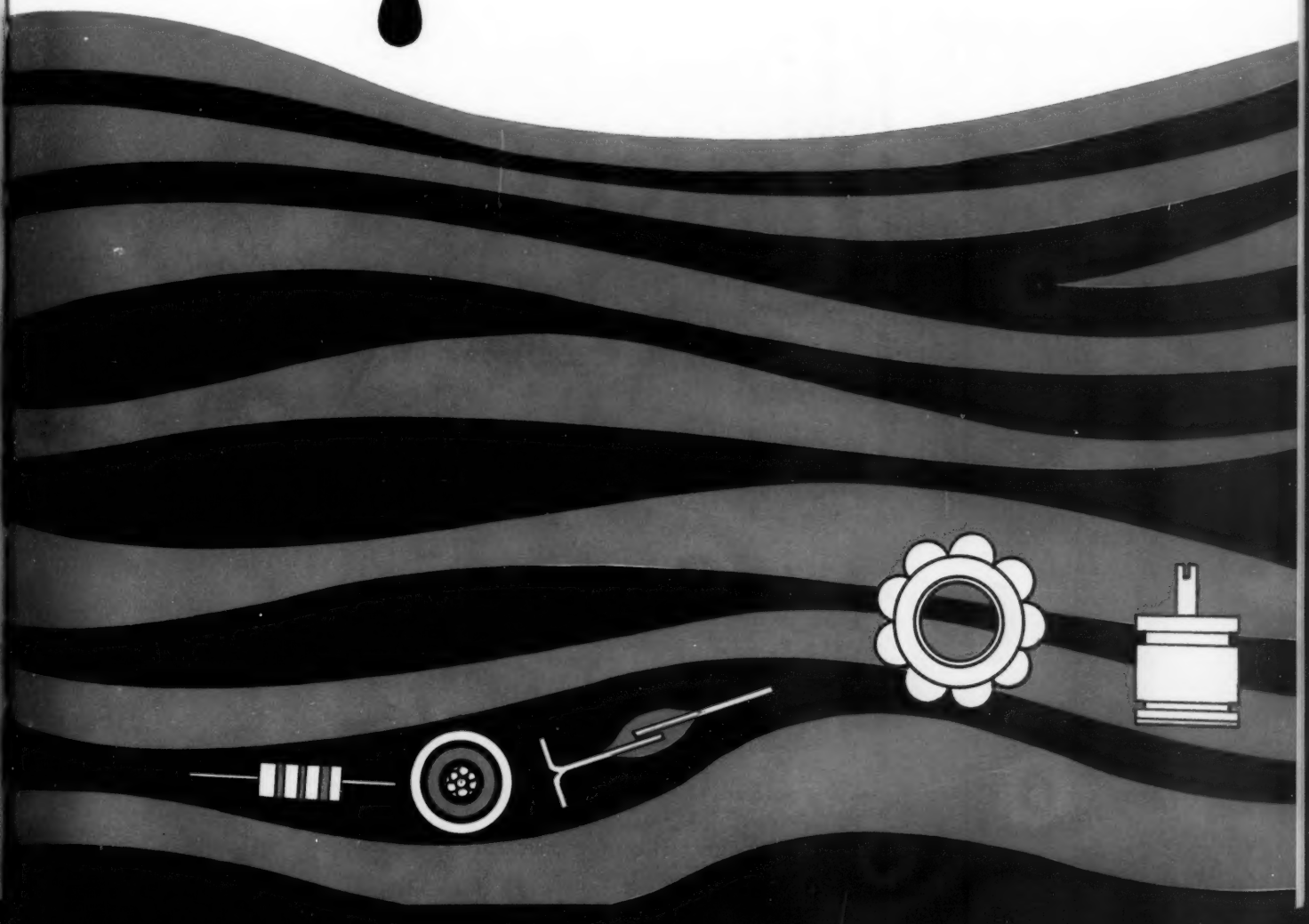
R.E.Carroll, Ass't.Dir.
The University of Michigan
Ann Arbor, Michigan

ELECTROMECHANICAL components & systems DESIGN

DECEMBER 1959

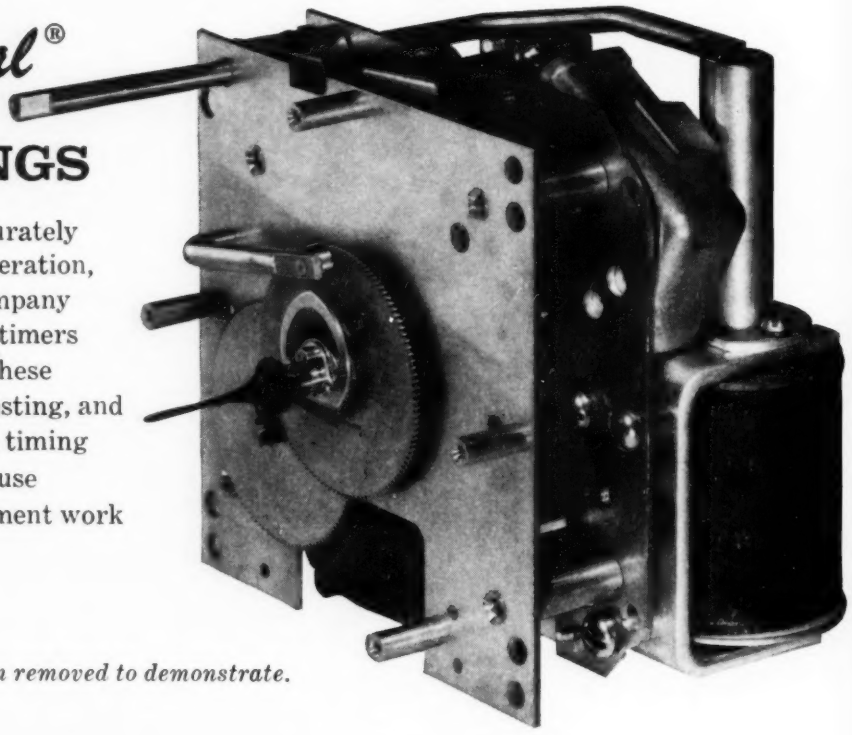
in this issue · components digest 10 · high temperature components



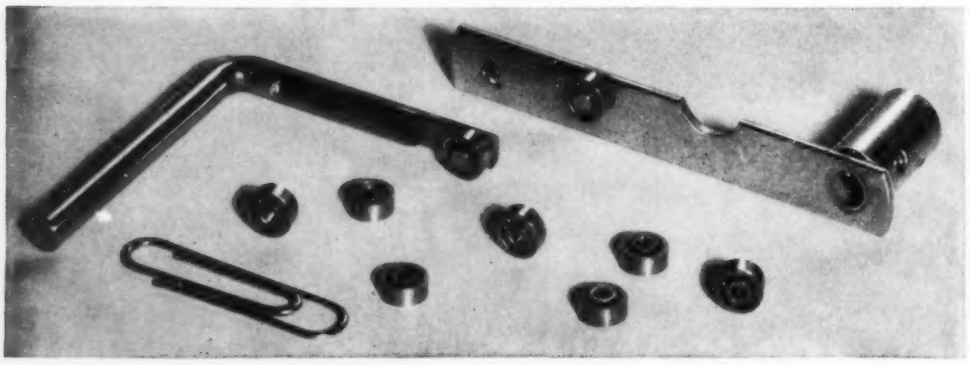
TIME AND PRECISION BEARINGS

HEIM *Unibal*®
MINIATURE
BALL BEARINGS

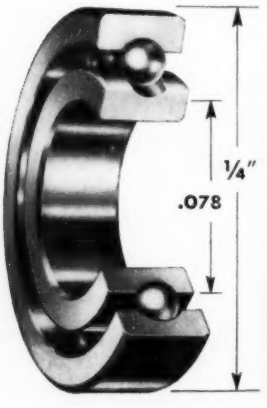
For measuring elapsed time accurately to within .001 of a second per operation, The Standard Electric Time Company manufactures precision electric timers which "split the split second". These timers are used in laboratory, testing, and production work wherever close timing is a requisite. Thousands are in use whenever research and development work must be accurately timed.



Dial and case have been removed to demonstrate.



Heart-shaped cams are attached to both hands of the timer. Miniature Heim Ball Bearings act as cam drivers, or friction-free rollers, to reset the timer after each use.



Unibal Ball Bearings Now Available in Miniature Sizes.

The simplified construction of the Heim Ball Bearing permits its assembly with just the inner and outer races and a full complement of balls. Insertion grooves, retainer rings, and spacers are eliminated.

Shown above are bearings with flush races, bearings with extended inner races for clevis mounting. The two reset arms, as used by Standard, indicate the method of mounting the bearings.

THE HEIM COMPANY

FAIRFIELD, CONNECTICUT

Save money on your ball bearing requirements with Heim Unibal.

HEIM BEARINGS ARE SOLD BY THE MOST RESPONSIBLE BEARING DISTRIBUTORS IN THE U.S. AND CANADA

CIRCLE 1 ON INQUIRY CARD

The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3 NO. 12

DECEMBER 1959

ELECTROMECHANICAL components & systems DESIGN

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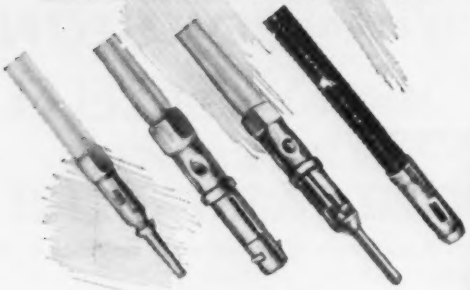
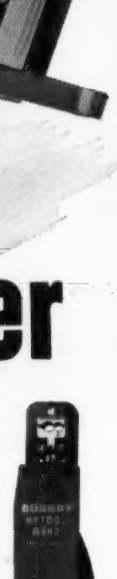
BURNDY
Electrical Contacts



and BURNDY
Installation Tooling

Designed for each other

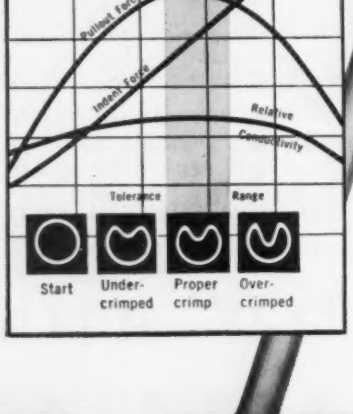
HYPRESS® YD
A semi-automatic pneumatic tool for installing contacts. Contacts are supplied in expendable plastic carry strips. The tool can be operated as a portable tool, or hand or foot operated as a bench-mounted tool. Full cycling control insures uniform completion of each installation.



HYTOOL® M8ND
A manual tool with removable dies. Ratchet action insures that dies close completely and thus eliminates the possibility of incomplete connection.

HYPRESS Y8ND
A pneumatic portable tool for rapid installation of contacts. Removable dies are interchangeable with M8ND. Full cycling control insures uniform completion of each installation.

TOOLS / CONNECTORS MATCHED BY WORK CURVE STUDIES



Laboratory work curves like this establish the proper type and depth of indent for every type of connector and wire. This depth then becomes an inherent characteristic of a full cycling control tool, guaranteeing a uniform and complete crimp each time a contact is installed. Thus the tool contributes to the built-in reliability of contacts and tooling **designed for each other.**

For details on these and other Burndy tools, write
OMATON DIVISION

BURNDY

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CIRCLE 2 ON INQUIRY CARD

ELECTROMECHANICAL
components & systems DESIGN

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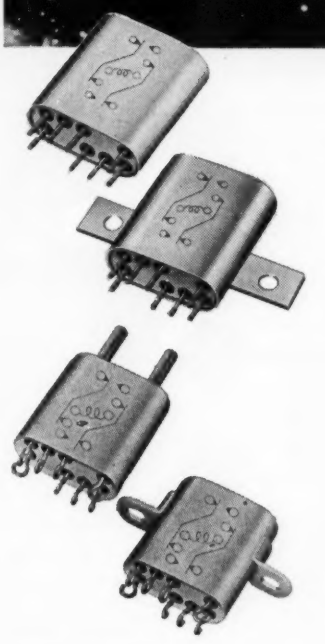
crystal can size relays by ADVANCE



—*these construction features assure exceptional reliability:*

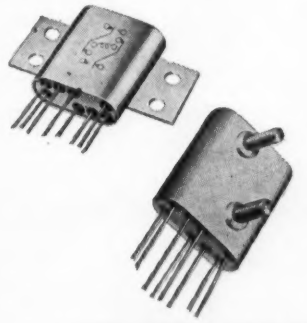
Positive sealing. Advance's use of induction heating cuts rejects from faulty soldering to a negligible figure. Soldering is accomplished at high speed, hence damage to the relay due to heat transfer is eliminated.

RADIFLO testing for leakage is used to detect leaks as small as 10^{-8} cc/sec. All relays that pass this test will function after long shelf life.

RIQAP* program approval. Under RIQAP, the Signal Corps constantly checks Advance's quality control and inspection, to insure military standards of reliability for all Advance customers, both military and industrial.

*Reduced Inspection Quality Assurance Plan of the U.S. Army Signal Corps.

ADVANCE MV SERIES
offered in 3 terminal arrangements...6 mounting arrangements, and 7 resistance values (30 to 10,000 ohms).
—AVAILABLE AT ADVANCE DISTRIBUTORS



SPECIFICATIONS

Coil resistance:	Available in 7 values, from 30 to 10,000 ohms.
Shock:	50 G's for 11 milliseconds.
Vibration:	10 to 34 cycles per second at maximum excursions of .4". 34 to 2000 cps 20 G's acceleration.
Operating power:	Pull in power 250 milliwatts at 25°C.
Contact rating:	2 amps resistive at 32 VDC or 115 VAC.
Life:	100,000 operations minimum at rated current.
Weight:	0.45 ounce.
Size:	7/8" high x 51/64" wide x 23/64" deep.

Our Applications Engineering Dept. will be pleased to work with you on your special application problems.

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ELGIN
A PRODUCT OF ELECTRONICS DIVISION
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CIRCLE 3 ON INQUIRY CARD

a complete range of brush materials for printed circuit applications.

Because the correct choice of contact materials for use on printed circuits is wholly dependent upon such factors as type of circuit, circuit function and mechanical design, the final selection of materials is generally obtained on an empirical basis.

Baker engineers and metallurgists are prepared to offer very broad, specialized experience, together with extensive records of performance data that can be extremely useful to you. They will be pleased to assist in resolving your particular problems in this field.

Baker-developed alloys and powdered metal products meet the full range of brush material requirements for printed circuit applications. Complete facilities are available here for reliable design and manufacture. Send for literature.

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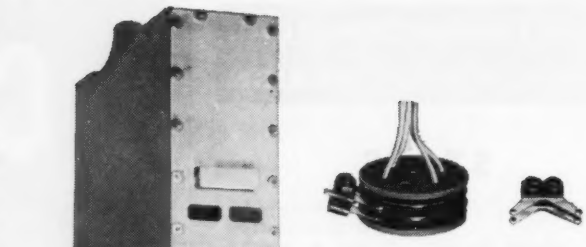
recognized leadership in the design and manufacture of slip ring assemblies.



The country's leading producers of electrical and electronic equipment look to Makepeace for the design and manufacture of slip ring assemblies.

Slip ring design for particular applications depends upon the various electrical and mechanical factors involved. Thus, Makepeace has developed many special alloys and combination of alloys to meet a wide range of requirements. Our engineers and metallurgists are thoroughly qualified in this specialized field and will be pleased to make recommendations on your particular problem.

Complete facilities are available for the manufacture of slip ring assemblies ranging in diameter from 1" to 48" and larger—for General Purpose, Radio Frequency and Video Ring Circuits, High Speed Instrumentation, High Voltage Ring Circuits and Power Pulse Slip Rings. A slip ring data file is available—write for your copy.

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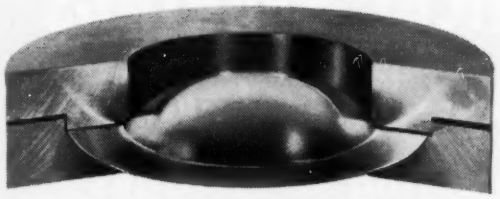
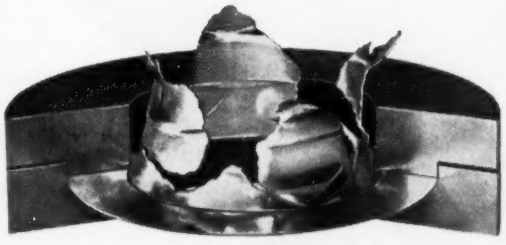
CIRCLE 4 ON INQUIRY CARD

CIRCLE 5 ON INQUIRY CARD

corrosion-resistant rupture discs for dependable instant and automatic relief of excess pressure





In pressurized apparatus subject to corrosive action, precious metal rupture discs provide the safest, most accurate and dependable relief. Platinum, gold, and silver are now generally recognized as specifics when dealing with corrosion. Each is resistant to the corrosive effects of an important group of liquids and gases and will remain unattacked under conditions that would render many base metal materials useless. These rupture discs, depending on material selected, are guaranteed to be burst ± 5% of specified pressure. Intrinsic value adds to the original cost of these discs but the actual metal value is recovered, no matter how torn or battered the discs may be. Send for Bulletin.

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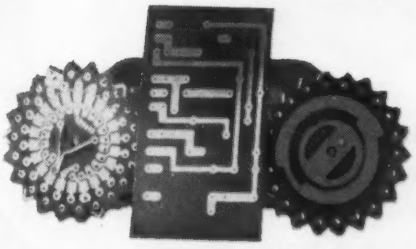
gold and rhodium plating for corrosion-resistant surfaces



ATOMEX® is a 24k gold immersion solution that permits the deposition of a thin, dense, uniform layer of 24k gold on printed circuits and metallized plastics by means of a simple bath. The Atomex procedure is more permanent and less expensive than electroplating of comparable thickness. Costly analytical control is unnecessary.

Rhodium—a complete line of plating solutions are also available for high-reliability electrical and electronic applications. Rhodium is highly resistant to corrosive atmospheres, oxidation and arc erosion—reduces wear on moving surfaces—assures low noise level for moving contacts, no oxide rectification, low and stable contact resistance. Rhodium plating is indicated when a low-resistance, long-wearing, oxide-free contact is required. Send for literature.

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CIRCLE 6 ON INQUIRY CARD

CIRCLE 7 ON INQUIRY CARD

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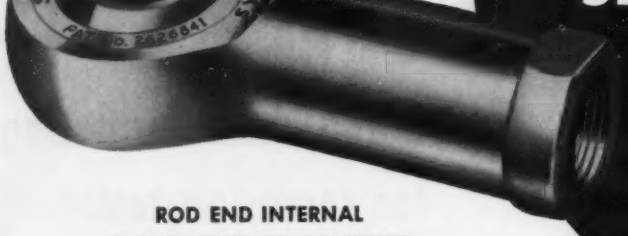
"Dyflon"®

Self-Aligning and Self-Lubricating SPHERICAL BEARINGS

Combine "Monoball"® Engineering Advantages with Life-Time Lubrication



ROD END INTERNAL THREAD TYPE "DREF" SERIES

Design engineers in many industries are specifying new "DYFLON"® SELF-ALIGNING and SELF-LUBRICATING SPHERICAL BEARINGS for these 5 major reasons:

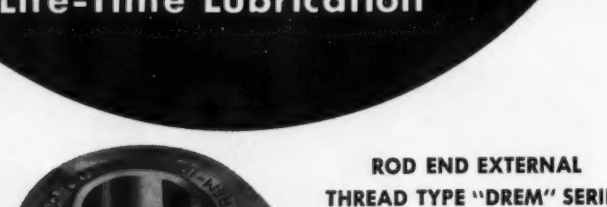
1. LOWER COEFFICIENT OF FRICTION ... ideal where lubrication is impossible or undesirable.

2. WITHSTAND EXTREME VIBRATION ... perfect performance under shock load conditions.

3. WILL NOT "COLD-FLOW" ... even under extreme load conditions.

4. IMPERVIOUS TO KNOWN CHEMICAL SOLVENTS ... eliminates corrosion problems.

5. FAIL SAFE ... due to "Monoball"® design.



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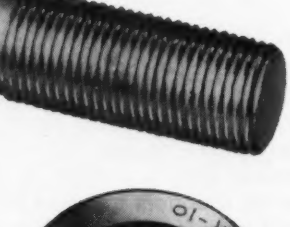

"LF" SERIES

In addition, due to their two-piece "MONOBALL"® design and plastic alloy insert, "DYFLON"® bearings have a long cycle life. Alignment and installation problems are minimized. Oil-free for life means lowest possible maintenance costs.

Available in a variety of plain or rod end types. Bore sizes to 3.000". Materials include stainless steel, plastic alloys and chrome alloy steels. Ultimate static loads to 500,000 lbs.

Engineered to the same high standards as Southwest's popular "MONOBALL"® Self-Aligning Bearings.

SOUTHWEST "DYFLON"® "Monoball"® bearings can solve your difficult alignment and installation problems. Request Engineering manual No. 551.

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RELIABLE PRODUCTS

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1705 SO. MOUNTAIN AVE. • MONROVIA, CALIF. • PHONE: MURRAY 1-9616

CIRCLE 8 ON INQUIRY CARD

Important news for owners of CEC's 5-114 recording oscillograph

NEW RAPID-ACCESS DATARITE MAGAZINE

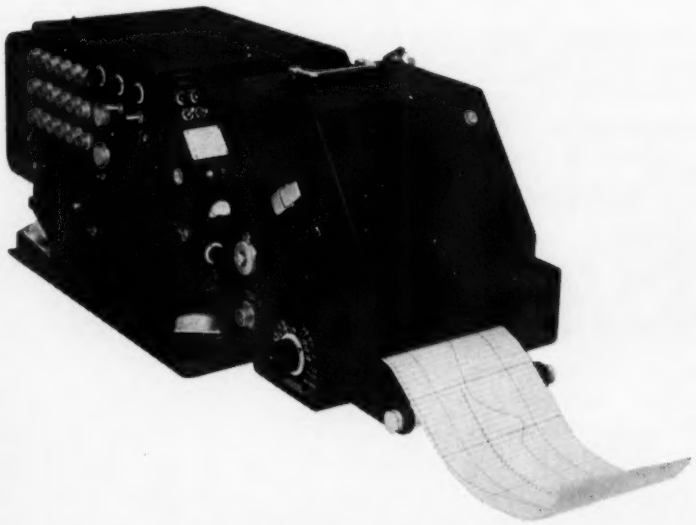
provides developed, dried, fully visible records almost instantly

Here is the DATARITE Magazine many of you owners of CEC's 5-114 Recording Oscillograph have been waiting for: The new 5-047. This DATARITE Magazine attaches directly to your 5-114. The result is a data-processing tool with all the capabilities needed for modern dynamic tests—especially attractive for low-budget programs.

RAPID-ACCESS . . . THE 5-047 DATARITE Magazine provides the shortest access time of any known process, and yields records of high trace contrast and permanency. The Magazine automatically develops and dries oscillograms as quickly as data are recorded. Ready-to-read test results are available almost simultaneously with the occurrence of events under study.

The 5-047 recording speeds are variable from .45 to 28.8 ips. Fully developed and visible record is available in 0.7 second at 28.8 ips record speed. There is a generous capacity of 400 feet of conventional thin-base recording paper, combined with writing speeds up to 20,000 ips. Power requirement is 115 v, 60 cps, 1500 watts for the combination of the 5-047 and the 5-114.

For complete details call your nearest CEC sales and service office, or write for Bulletin CEC 1500-X28.



Electro Mechanical Instrument Division CEC

CONSOLIDATED ELECTRODYNAMICS *360 Sierra Madre Villa, Pasadena, California*

CIRCLE 9 ON INQUIRY CARD

Largest selection

Trimpot®

the original leadscrew-actuated potentiometer

More engineers specify Trimpot because:

Trimpot line is complete

Bourns offers you the largest selection of leadscrew actuated potentiometers... 20 basic models—4 terminal types—three mounting methods.

Trimpot is small

Space saving size and rectangular shape permit the installation of 12 to 17 units in one square inch of panel area.

Trimpot is accurate

Multi-turn screwdriver adjustment provides 9000° of rotation...you can make and repeat the finest adjustments.

Trimpot is stable

Adjustment shaft is self-locking...settings are virtually immune to severe acceleration, vibration and shock.

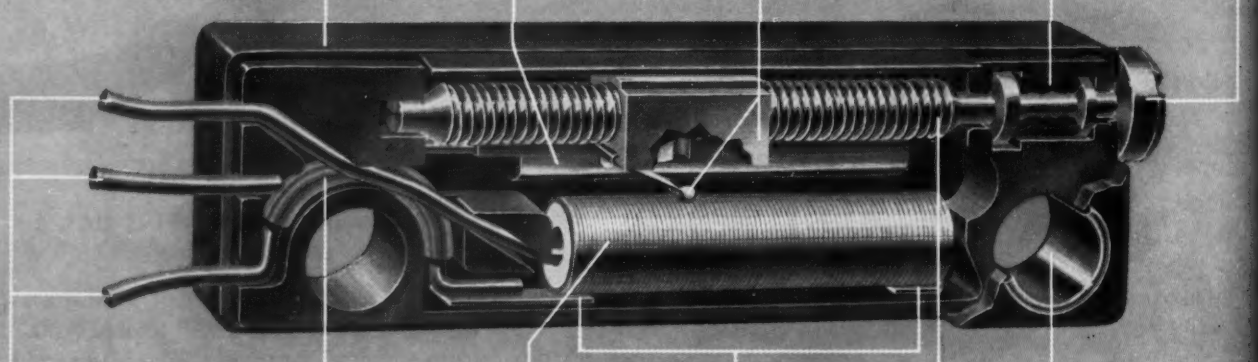
Trimpot is fully tested

All instruments are 100% inspected before shipment to assure you of reliable performance.

Trimpot is proved

It is used in more military and commercial equipment than any other leadscrew actuated potentiometer.

Only Bourns Trimpot potentiometers give you these outstanding features



BODY—High-temperature, thermosetting plastic body is sealed, enabling potentiometer to meet Mil-Specs for humidity, sand, dust, fungus, salt spray, etc.

COLLECTOR BAR—Precious metal collector bar provides positive electrical contact, improves potentiometer performance and reliability.

WIPER CARRIAGE—Special high-temperature plastic carriage with precious metal contact spring permits exact settings and stability under severe environmental conditions.

SHAFT HEAD—Stainless steel with machined slot for screwdriver adjustment. Meets military salt spray requirements.

O-RING—Silicon rubber O-ring seals potentiometer against humidity, withstands high temperature.

TUBING INSULATION—Tubing around terminal eliminates possible short or electrical cross-over.

SILVERWELD* TERMINATION—This exclusive Bourns feature is unequalled in ruggedness. There is a metal-to-metal bond from the terminal to the resistance wire.

EYELETS—Stainless steel eyelets are set on ¾" centers and provide easy mounting with 2-56 screws.

TERMINALS—Three terminals are gold-plated copperweld wire or Teflon-insulated leads.

ELEMENT—Special ceramic mandrel is precision wound with low temperature coefficient resistance wire.

LEADSCREW—Stainless steel leadscrew is corrosion resistant, withstands salt spray.

*TRADEMARK

This cutaway of Model 220 is typical of the design of all Bourns Trimpot potentiometers though some features may vary from model to model.

CIRCLE 10 ON INQUIRY CARD

Longest record of reliability

General Purpose Wirewound Trimpot—Model 200. Operates at 105°C / L,S,P terminals / 1/4 watt / 10 ohms to 100K. Available as rheostat, Model 201.

High-Resistance Wirewound Hi-R® Trimpot—Model 207. Operates at 175°C / L terminal / 2 watts / 100 ohms to 100K. Available as rheostat, Model 208 Hi-R Trim R®.

Dual-Element Wirewound Twinpot®—Model 209. Operates at 105°C / L terminal / 1/4 watt / 10 ohms to 20K. Two potentiometer outputs with one adjustment shaft.

General-Purpose Carbon Trimpot—Model 215. Operates at 125°C / L,S,P terminals / 1/4 watt / 20K to 1 Meg. Available as Mil-Spec humidity-proof unit, Model 235 (1K to 10 Meg).

Subminiature Wirewound Trimpot—Model 220. Operates at 175°C / L & W terminals / 1 watt / 100 ohms to 20K. Meets Mil-Specs for humidity.

High-Temperature, Humidity-Proof Wirewound Trimpot—Model 224. Operates at 175°C / L,S,P terminals / 1 watt / 100 ohms to 100K. Meets Mil-Specs for humidity.

Humidity-Proof Wirewound Trimpot—Model 236. Operates at 135°C / L,S,P terminals / 0.8 watt / 10 ohms to 100K. Meets Mil-Specs for humidity.

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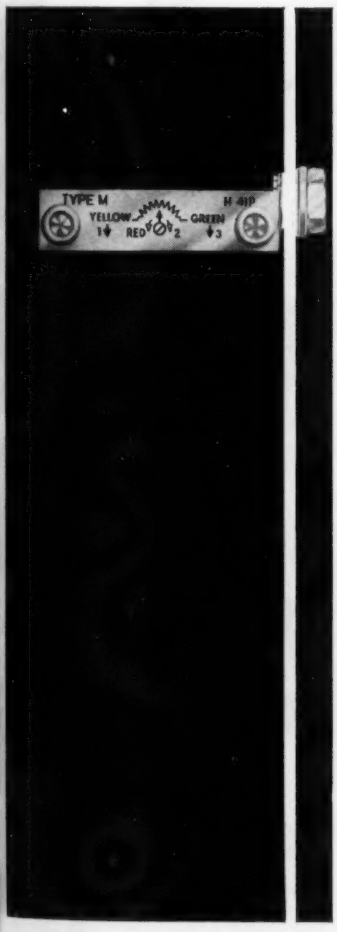

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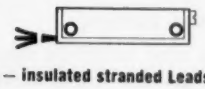
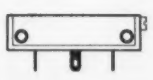
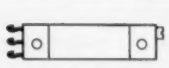


L — insulated stranded Leads

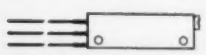


S — Solder lugs



S — Solder lugs (Model 224 only)

P — Printed circuit Pins



W — uninsulated Wires

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20	100	500	2K	10K	50K	200K	1Meg

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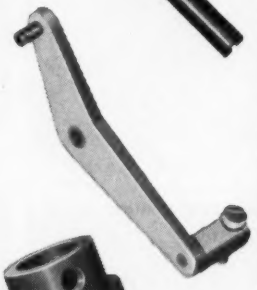

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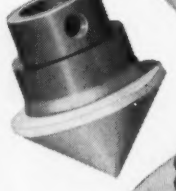

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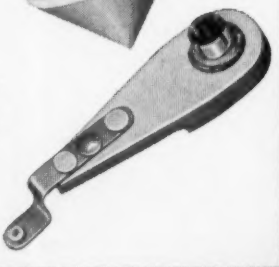

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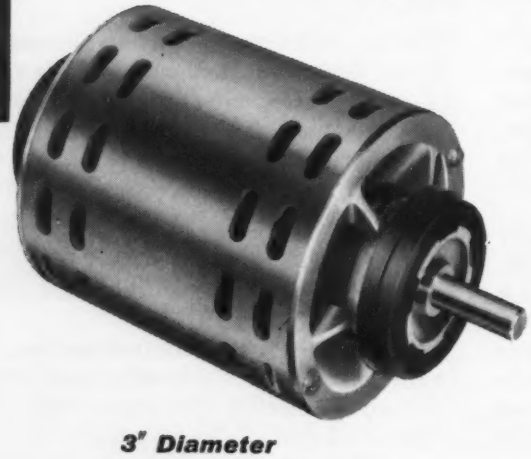

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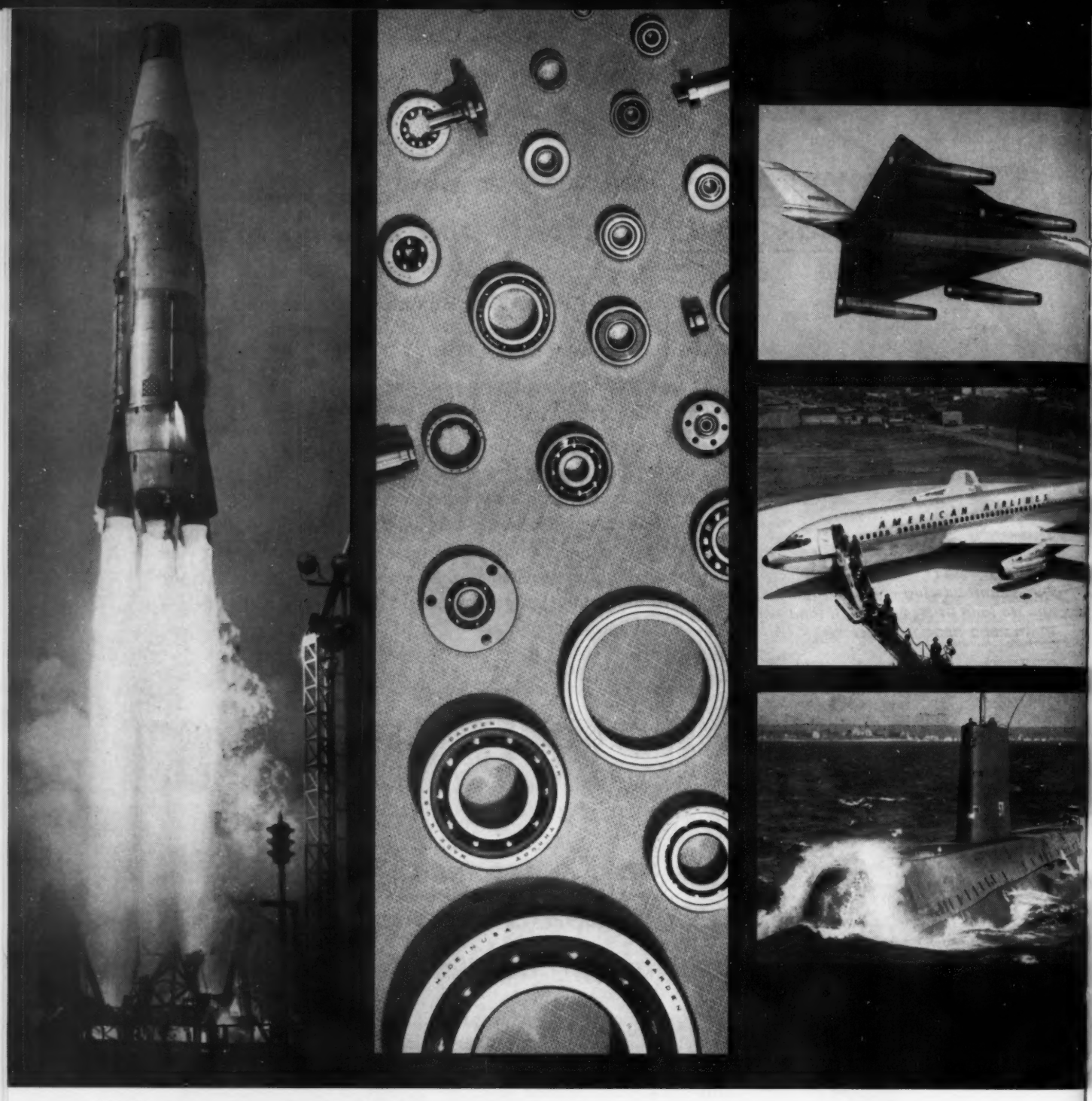

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CIRCLE 14 ON INQUIRY CARD

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A new method for producing high-voltage a-c or d-c electrical power recently developed by the International Telephone and Telegraph Corp., is based on the known phenomenon that the permittivity or dielectric constant of certain ferro-electric materials varies

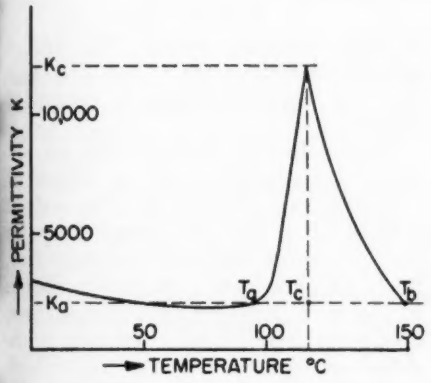

Fig. 1—Permittivity of barium titanate around Curie temperature T_c

with temperature. The temperature at which the maximum dielectric constant occurs is known as the Curie point. The permittivity curve of one of these dielectrics, barium titanate, is shown in Fig. 1 to illustrate this point.

The operating principle and the basic circuit of the ferroelectric energy converter can be described with the aid of Figure 2. The main element is a large capacitor with a dielectric consisting of a suitable ceramic ferroelectric material such as barium titanate. This capacitor is maintained in a charged state by a battery or other source through a holding diode with

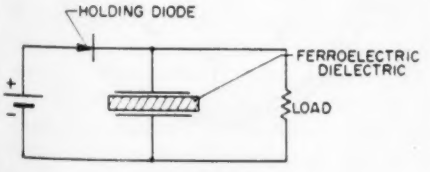

Fig. 2—Basic circuitry of ferroelectric energy converter

a high back voltage. If the capacitor is at the Curie temperature T_c, its capacitance C_c is at a maximum due to the high permittivity K_c. Its electrical charge is

$$Q = C_c \cdot V_c$$

where V_c is the voltage of a d-c source such as a battery. The electrical energy stored in the capacitor is given by

$$W_c = 1/2Q \cdot V_c$$

If the capacitor is cooled to a temperature T_a or heated up to T_b, its permittivity drops to K_a or K_b, respectively, as shown in Figure 1. There is a corresponding drop in capacitance to

$$C_a = (K_a/K_c)C_c$$

Since the charge Q cannot decrease because of the diode, there must be a rise of capacitor voltage from V_c to V_a by the factor (K_c/K_a), due to the requirement:

$$Q = C_c \cdot V_c = C_a \cdot V_a$$
$$= (K_a/K_c) \cdot C_c \cdot (K_c/K_a) \cdot V_c$$
$$= \text{constant.}$$

Hence, the capacitor voltage has been stepped up by the cooling or heating of the capacitor. This increased voltage also means an increase of electrical energy W by the factor (K_c/K_a) because

$$W_a = \tfrac{1}{2} Q V_a = \tfrac{1}{2} Q V_c (K_c/K_a)$$

The energy increase

$$\Delta W = W_a - W_c$$
$$= \tfrac{1}{2} Q V_c [(K_c/K_a) - 1] = \tfrac{1}{2} Q \Delta V$$

is due to the conversion of thermodynamic or heat energy into electrical energy.

It should be noted that a permittivity curve as in Figure 1 does not quantitatively describe the energy gain. This is due to the fact that the permittivity is dependent on the elecrical field strength which changes during a temperature cycle. The permittivity curve given in Figure 1 is applicable only with a low applied voltage or field strength. Practical energy converters operate at higher levels of field strength, in which case the permittivity has no appreciable drop, if any, below the Curie temperature. The converter, consequently, is operated between the Curie temperature and a higher temperature.

To further illustrate the operating mechanism of the ferroelectric energy converter, a 2-plate capacitor with air dielectric can be used and charged as in Figure 2. Moving both capacitor plates apart will also increase the voltage according to the decrease in capacitance as shown above. The only difference is the mechanism of the capacitance change. Again, the energy increase is

$$\Delta W = \tfrac{1}{2} Q \Delta V$$

The energy ΔW has been supplied, in this case, in the form of mechanical work expended by pulling the capacitor plates apart against the electrostatic attracting force.

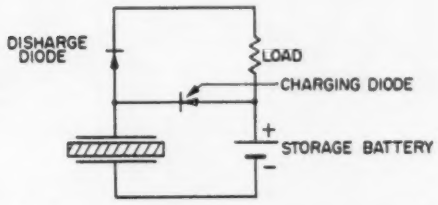

Fig. 3—Ferroelectric energy converter circuit requiring no primary battery

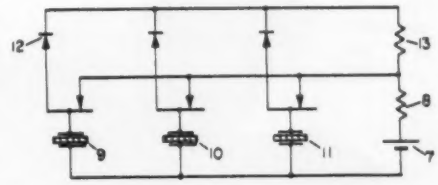

Fig. 4—Multiple capacitor converter

Both this model as well as the ferroelectric energy converter can be looked at as parametric amplifiers for d-c signals. The battery of Figure 2 has simply to be treated as a d-c input signal which is to be amplified. Voltage and power gain are as derived above. The frequency of capacity variation is equivalent to the "pump" or power frequency.

BATTERY POWER ELIMINATED

Ferroelectric energy converters do not have to use up battery power as is the case in the circuit described above. One way of eliminating the need of battery power is to use a storage battery in series with the load. Such a circuit is shown in Figure 3. A storage battery charges the converter capacitor over a charging diode. After heating, the stepped-up voltage is fed through a discharge diode, a load, and the storage battery. Thus, the electrical charge Q is returned to the battery. The load itself could be a storage battery which would act as a buffer.

Another way of eliminating battery power is shown in Figure 4. Battery 7 serves only to initially charge or "prime" a multitude of converter capacitors 9, 10, and 11) and to overcome leakage in these capacitors. A high value charging resistor 8 or a

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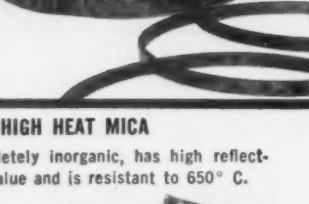

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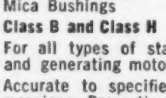

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diode is used in series with the battery in order to prevent the discharge of output currents through the battery. Converter capacitors 9, 10, and 11 are temperature cycled in such a fashion that they are at different points of the cycle at a given moment. Assuming capacitor 9 at temperature T_b and capacitor 10 at T_c, a discharge of 9 over diode 12, load 13 and a charging of capacitor 10 will take place. In the next step, capacitor 10 will discharge and charge capacitor 9 and/or 11. In this fashion, the total charge is recirculated between the capacitors, resulting in a d-c current through load 13.

HIGH-VOLTAGE GENERATORS

Ferroelectric energy converters inherently have higher output voltages than other known converters. The output voltage is given by

$$V_b = V_c(K_c/K_b)$$

A high charging voltage, V_c, and a suitable material with a high (K_c/K_b) result in output voltages in excess of 1000 v.

Extremely high voltages can be obtained by cascading several stages of converter capacitors so that the output voltage of a preceding stage may be used to charge the following capacitor. Such a high-voltage generator is shown in Figure 5. Four converter capacitors, 20-23 are attached to a rotating cylindrical or spherical body, 24, which forms a common outside electrode. It is assumed that the cylinder is heated at the top to a temperature T_b and cooled by a heat sink or by radiation to a temperature T_c. The optimum output voltage, V_n, of a converter with n capacitor stages is given by $V_n = V_c(K_c/K_b)^n$, where V_c is the voltage of battery 27. In the example shown, $n = 4$, so that the output voltage becomes $V_c(K_c/K_b)^4$. The electrical

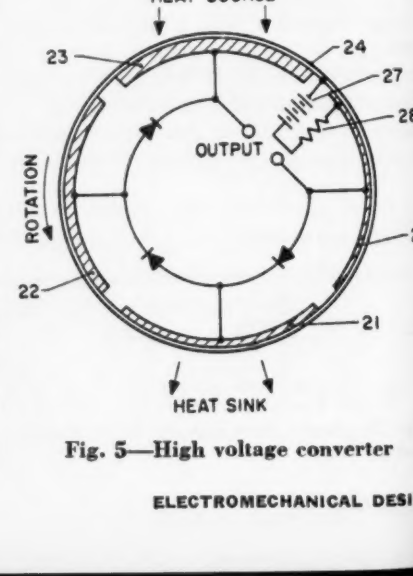

Fig. 5—High voltage converter

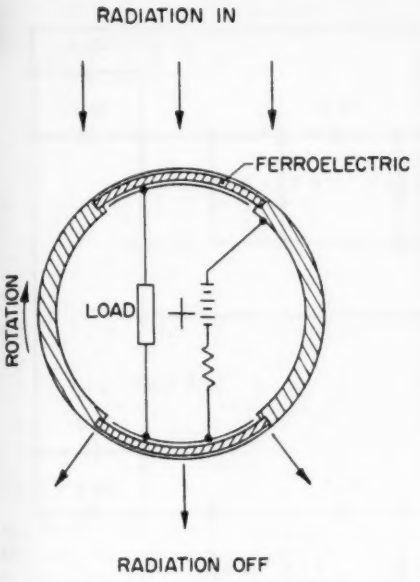

Fig. 6—A-C generator

charge Q is fed back into capacitor 20 and recirculated. Battery 27, consequently, supplies only the initial charge and leakage losses as in the case of Figure 4.

A device as shown in Figure 5 lends itself particularly well for satellites or space vehicles which can easily be made to spin and use solar energy. The high voltage can be used as energy source for ion propulsion.

A-C GENERATORS

Since the new ferroelectric energy converter requires temperature cycling of ferroelectric capacitors, it is ideally suited for the generation of alternating currents. The principle of an a-c generator is shown in Figure 6. It shows a section through a rotating cylindrical or spherical body such as a spinning satellite. Two large ferroelectric converter capacitors are arranged on opposite sides of the satellite so that one is heated by incoming solar radiation while the other is cooled through radiation. The outside electrodes of both capacitors are on common ground. The inside electrodes are connected through a load. The capacitors are charged initally by a battery and resistor. This electrical charge is driven back and forth through the load as both capacitors are heated and cooled alternately. The battery has only to supply the leakage currents which can also be obtained from a rectified output. It should be noted that the electrical energy dissipated in the load is derived from the temperature cycling of the ferroelectric capacitors, and not from the rotational energy of the body as in conventional electromagnetic generators.

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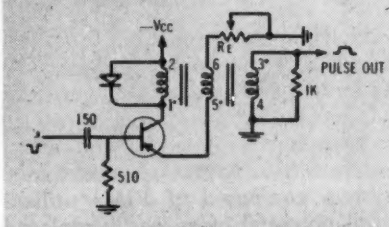

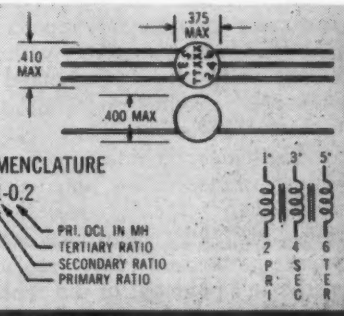

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.22	3	.02	30	−6	−1	2N240	TT421-0.2
.3	6	.06	20	−6	−1	2N240	TT331-0.2
.5	6	.05	25	−6	−1	2N240	TT221-0.5
.6	6	.05	15	−6	−1	2N240	TT331-0.5
.9	6	.06	10	−6	−1	2N240	TT661-1
1.2	6	.04	20	−6	−1	2N240	TT331-1
1.5	6	.2	20	−6	−1	2N240	TT221-1.5
2.2	10	.09	50	−12	−1	2N247	TT661-1
12	5	.05	50	−12	−1	2N247	TT521-6
13	2.5	.03	25	−6	−1	2N240	TT521-6

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FAILURE-INDICATING MODULES

Keeping Complex Systems Operational

A unique type of waveform analysis is now possible by using a new waveform sampling device called a comparator network; sufficient numbers of these devices may be used to synthesize large systems capable of analyzing their own operation. The use of modular construction makes it easy for relatively unskilled personnel to restore normal system operation by the simple expedient of replacing a bad unit with an available spare. The defective unit may then be referred to a depot where specialists in a particular type of assembly can make the necessary repairs at a fairly even pace, compared with the peak and valley type of demand for maintenance personnel prevalent at the system level. However, as systems become increasingly complex, more skill and time are needed to pinpoint any malfunction to a specific area. If 90% of the down time is spent locating the defective parts and 10% replacing them, the full potential of the replaceable module is not being used.

FAILURE-INDICATING MODULES

In a series of recent papers, W. B. Bishop introduced the concept of the Failure - Indicating Module (FIM) which he defined as follows: The Failure-Indicating Module is any assemblage of electronic parts capable of indicating its own failure. While an ordinary module is a device or black box that is capable of performing some specific equipment function, a corresponding FIM not only performs the same equipment function, but provides a suitable indication of the go—no go type to indicate when the equipment function is not within specific limits. A system composed of FIMs utilizes the full potential of an easily replaced device and can be maintained at the system level by relatively unskilled personnel.

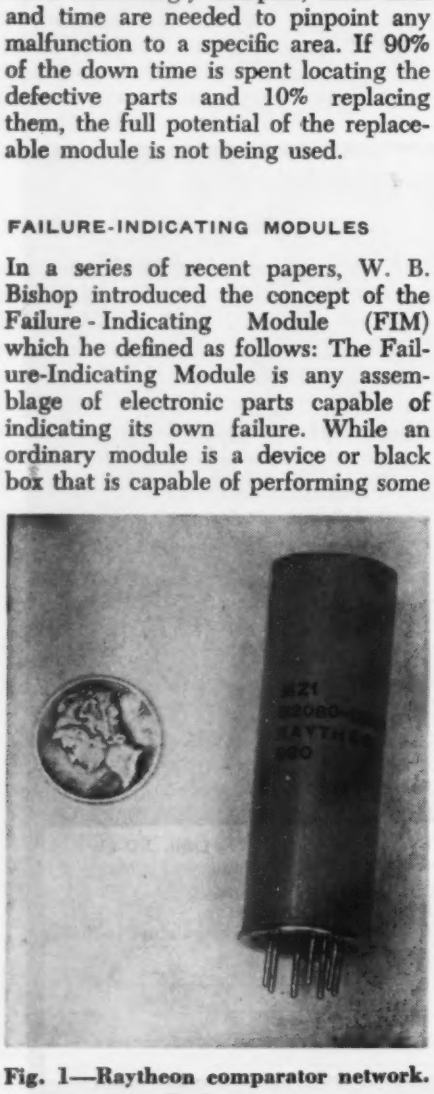

Fig. 1—Raytheon comparator network.

Bishop listed three considerations necessary in the design of a Failure-Indicating Module:

1. When or where failure indicators are needed.
2. Reliable means of failure indication each time a failure occurs.
3. Appropriate use of the failure indications which occur.

The need for failure indication at a particular point can be decided on the basis of the signal flow logic of the particular system. The effect of the absence of certain signals on system operation should be readily apparent in most cases. Past history of the reliability of a practical circuit will often enter into decisions as to whether or not a failure indicator is needed.

COMPARATOR NETWORK

The comparator network shown in Fig. 1 developed by Donald H. Breslow of Raytheon's Wayland Labs is a miniature encapsulated plug-in unit (7 pin miniature basing) which when used with externally supplied reference voltages allows continuous monitoring of the performance of two independent electronic signals, and causes an alarm to be actuated when either signal falls below a preset reference level. Here's D. H. Breslow's description of the operation and salient features of this device.

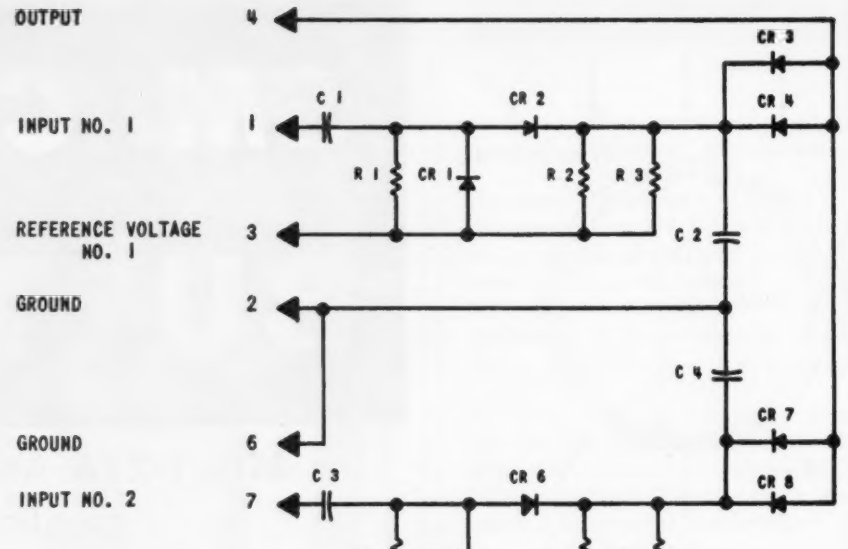

Fig. 2—Comparator network schematic.

Fig. 2 shows a schematic drawing of the comparator. This device consists of two independent peak detection-comparison networks with the outputs of each of the dual comparison networks coupled together through an "And" coincidence circuit to form a single normalized output. Channel 1 (consisting of C1, C2, CR1, 2, 3, 4, and R1, 2, 3,) and channel 2 (consisting of C3, C4, CR5, 6, 7, 8 and R4, 5, 6) are identical. For purposes of describing the operation of one of the peak detector-comparator sections of the device, channel 1 will be referred to.

A signal to be compared (monitored) is applied at pin 1 and is a-c coupled into the network through C1-R1 whose time constant is many times larger than the width of the widest gate to be handled. CR1, a d-c restorer to restore the level of the a-c coupled input to the value of the negative reference voltage, is applied at pin 3 and is derived from an external source. The restored signal charges C2 through CR2. The time constant of C2 and paralleled resistors R2 and R3, which constitute the discharge path for C2, is much greater than the period of the input signals so that the voltage across C2 is a relatively good peak detection of the input. The voltage across C2 (one terminal of C2 is grounded) represents the comparison (difference) of the peak amplitude of the input and the magnitude of the negative reference voltage. If the peak amplitude of the input is greater than the magnitude of the

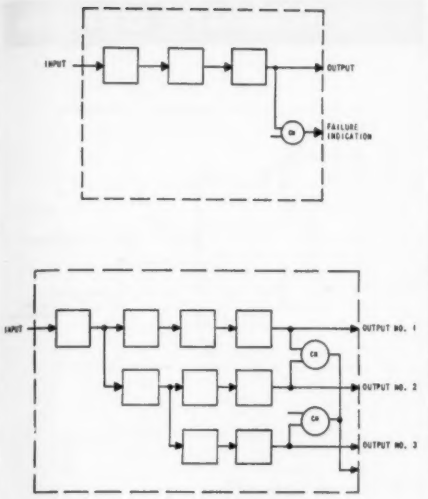

Fig. 3—Typical series connected modules can be quickly checked for failure location by simply monitoring the outputs with a comparator channel for each output signal. One comparator channel is required for the straight series connected module of Fig.3a; three comparator channels (two comparators) are required for the branching series connected module of Fig.3b.

reference, then C2 will be charged positively with respect to ground; if the peak amplitude of the input should be less than the magnitude of the reference, then C2 will be charged negatively with respect to ground.

The output terminal on pin 4 is normally terminated in 1 megohm to ground. When C2 is charged positively with respect to ground, parallel diodes CR3-4 are back biased, and the output at pin 4 is at ground potential (through 1 megohm). Should C2 not be charged above ground, as would be caused by a decrease in amplitude of the input signal, then parallel diodes CR3-4 are forward biased. They conduct through the path of the terminating resistor and parallel resistors R2-R3, and the output at pin 4 falls below ground by an amount proportional to the difference between the input signal peak amplitude and the magnitude of the negative reference voltage.

It can be seen that the output at pin 4 has two principal states; one state, at ground, corresponds to normal operation of the monitored circuits. A second state, below ground, corresponds to a malfunction or performance deterioration. A typical fail level is 1 volt negative or greater.

Regardless of the amplitude or shape of the waveform that is compared, or the level at which the input is judged to cause malfunction, the output of the comparator is zero volts for normal operation and minus 1 volt for malfunction. The effect of this device is to normalize any input so that the output state is at either of two prede-

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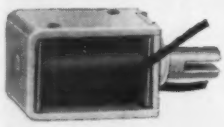

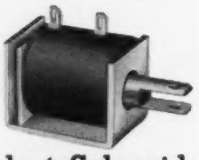

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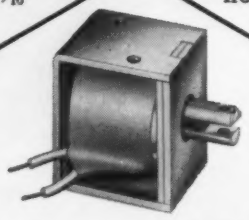

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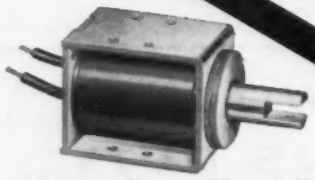

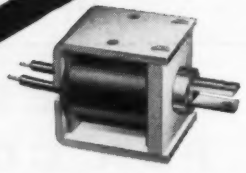

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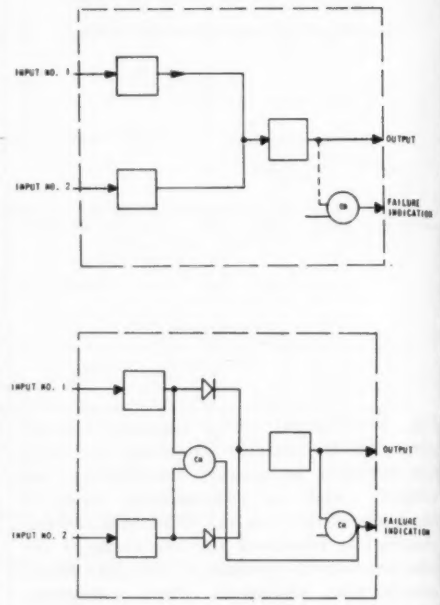

Fig. 4—The parallel logic module of Fig.4a is slightly more complicated to handle than the series type. If the comparator is placed at the output of the module, as shown in Fig.4a, the output of the comparator may not be a true reading of the operation of the whole module. The comparator is a peak detecting device so the signal from any one channel is able to saturate the device and exclude sensitivity to the other channel. In the condition where the comparator is saturated by the signal from one channel, a failure in the other channel will be undetected. If the mixed signals are redundant, then this condition may be acceptable. However, if the signals are not redundant and are both essential, then the configuration of Fig.4b may be used to isolate the signals before mixing. This requires the use of two additional comparator channels to check each signal before the signals are mixed. Note that the configuration of Fig.4b requires two additional mixing diodes; if either of these diodes short, the conditions of Fig.4a prevail. If the diodes open, system operation may be degraded in some cases.

termined levels. Normalizing is accomplished by supplying a suitable negative reference for each input waveform and by DC restoring each input signal to the reference level. For the output at pin 4 to be at ground, C2 must be charged positively, regardless of input wave, shape and amplitude. The setting of reference voltage establishes the level from which C2 is charged. When this level is set externally to the device, all waveforms can provide the same normalized output levels of 0 and −1 volt.

This device is a dual network. Up until now, channel 1 has been de-

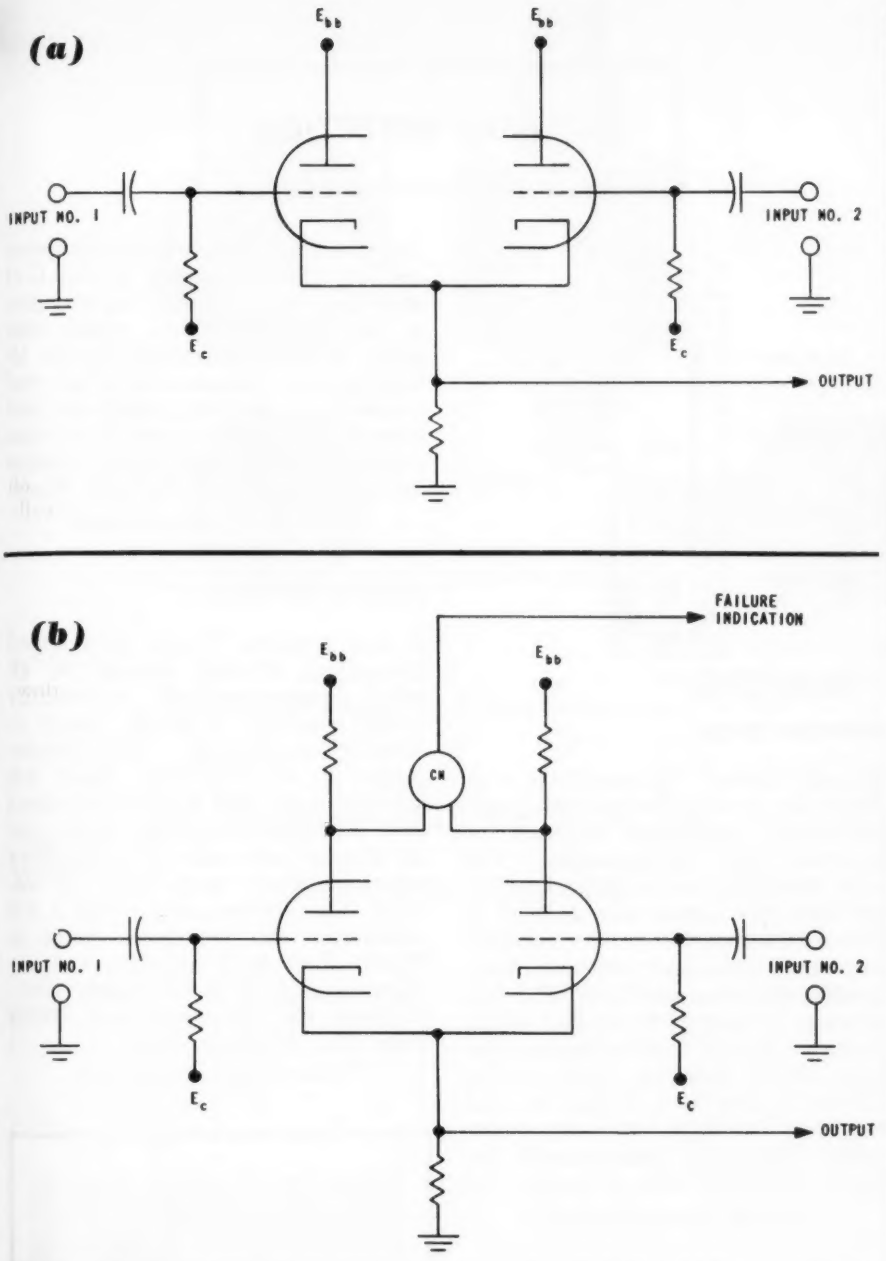

Fig. 5—It is often possible to generate a synthetic sampling signal for the comparators such that the operation of both circuits may be checked in a manner that will not degrade system performance. An example of this is shown in the cathode coupled mixer above. In Fig.5b small plate resistors have been inserted to obtain a sampling pulse for the comparators. These resistors do not affect circuit operation and are able to provide independent samp'ing pulses for each comparator. The two resistors fail safe, that is, if they open or short, failure will be shown by the comparators.

scribed. Channel 2 (signal input on pin 7 and reference bias on pin 5) operates exactly as does channel 1. The two peak detector normalizing channels operate completely independently of each other. However, the operation of the output circuits is not completely independent.

The voltage across C2 to ground represents the comparison of peak amplitude of the input at pin 1 and the magnitude of the reference at pin 3; the voltage across C4 to ground represents the comparison of the input at pin 7 and the reference at pin 5. The comparison voltage of channel 1 is coupled to the output at pin 4 through parallel diodes CR3 and 4; the comparison voltage of channel 2 is coupled to the output through parallel diodes CR7 and 8. Recalling that pin 4 is normally terminated in 1 megohm to ground, it can be seen that diode combinations CR3-4 and CR7-8, together with the terminating resistor from what is known as the "AND" coincidence circuit. Both sets or paralleled diodes, CR3-4 *and* CR7-8 must be back

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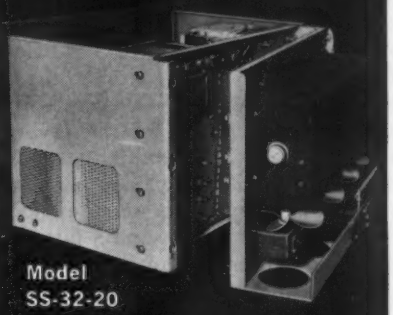

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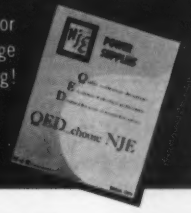

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biased (C2 *and* C4 must be both charged above ground) for the output to be at zero volts. Should either pair of diodes be allowed to conduct in the forward direction, as would be caused by reduction in amplitude of either input signal, then the output at pin 4 will be negative.

When only one signal is to be monitored, either channel of the device may be used since they are identical; both channels are used when two signals are to be monitored. If three or more signals must be monitored, then the number of comparators may be increased as necessary, remembering that each unit has two usable channels. When more than one unit is employed, the outputs on pin 4 must all be connected together; only one terminating resistor is needed regardless of how many comparators are used. The AND circuit output configuration makes "stacking" possible. Should any one signal out of many that are being monitored degrade below a certain preset limit, then the output will be in the "fail" state.

The comparator is primarily an amplitude comparison device. However, if a parameter such as rise time is deemed critical, then a simple high pass RC filter placed at the input of the comparator will permit an approximate measurement by sampling high frequency components of the signal. Similarly, a simple low pass filter will permit measurements of flatness of the tops of rectangular pulses.

The operation of the comparator may be summarized as follows: The comparator accepts as inputs up to two independent periodic electronic waveforms, compares each of these waves against its own externally supplied reference, and supplies an out in essentially binary form, 0 volts for normal and −1 volt for malfunction. Using as many of these devices as necessary reduces the performance state of a complex electronic device or sub-assembly to a single DC voltage.

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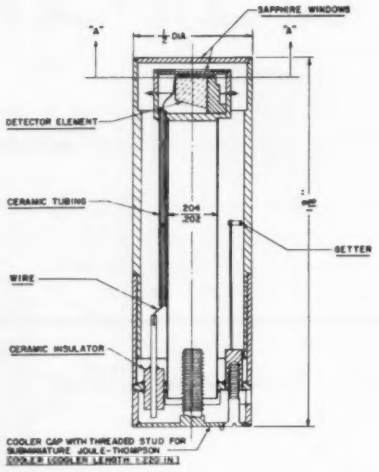

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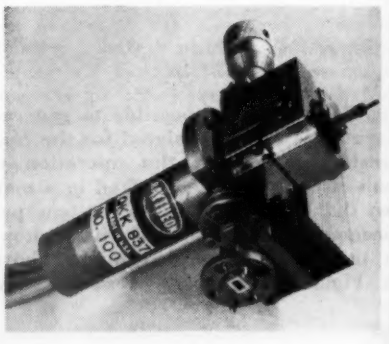

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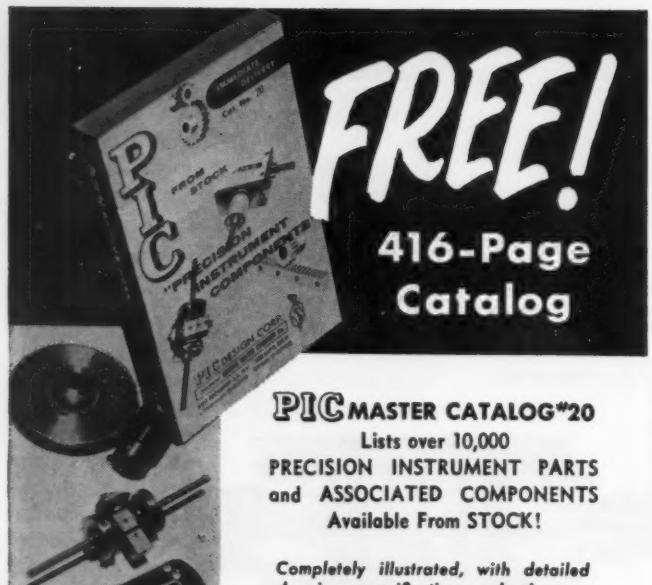
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A new series of pressure transmitters, designed for use in the primary loop of pressurized water nuclear reactors, sense pressure with high sensitivity and convert it to a linear electrical output suitable for indicating and control purposes.

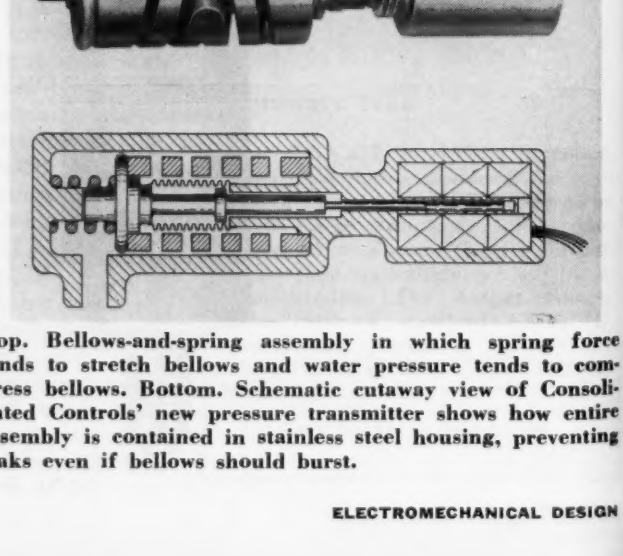
The sensing element consists of a bellows concentrically mounted within a spring. The bellows and spring are fixed at one end to the housing. The other ends of the spring and bellows are joined together and are free to move axially. Initially under compression, the spring tends to lengthen the bellows and applied water pressure tends to shorten it. A shaft, fixed to the moving end of the bellows, is positioned by the balance between spring and water pressure forces.

The other end of the shaft is attached to a built-in differential transformer core whose position controls the output of the two secondary transformer windings, Thus, electrical output is a direct function of water pressure. The difference between the voltages on the two secondary windings is used as the signal output, and the sum is used to maintain the input voltage to the transformer primary at its six-volt ac level. Units use a new type of spring which eliminates end effect and twisting, characteristic of conventional springs.

All mechanisms and, hence, all operating pressures are confined within an all-welded stainless steel housing; Carbon steels are used in units for non-nuclear applications. Magnetic coupling of the transformer windings eliminates moving seals. Units are available for pressure ranges from 0 to 500, 1,500 and 2,500 psi. Over-range protection to 3,750 psi provides protection against any abnormal pressure surges. Line pressure testing can be accomplished with the units installed.

Output voltages can be either ac or dc. On ac models, input voltage is 6 volts, 60-cycle with a power consumption of approximately one watt. AC outputs vary with pressure from 0 to ½ volt. For dc output the unit comes equipped with input voltage regulator and output rectifier. Input to dc models is 115-volt, 60-cycle ac; output is 1 volt dc minimum across 1,000 ohms with 1 milliamp of current max. Accuracy of all units is ±¾%. The transmitters meet the requirements of MIL-N-19900A. Consolidated Controls Corporation, Bethel, Connecticut.

Circle No. 83 on Inquiry Card.



Top. Bellows-and-spring assembly in which spring force tends to stretch bellows and water pressure tends to compress bellows. Bottom. Schematic cutaway view of Consolidated Controls' new pressure transmitter shows how entire assembly is contained in stainless steel housing, preventing leaks even if bellows should burst.

NEW MINIATURE ACCELEROMETER

High Performance At High Shock

A precision miniature accelerometer that will give exceptional performance under high shock and vibration conditions, is believed to be the smallest of its type (15/16" diameter; ⅞" long). Capability of withstanding 100g shock and 20g vibration over 50-2,000 cps is obtained as a result of two exclusive design features:

- The damping fluid which completely fills the instrument provides partial gimbal floatation permitting very high shock and vibration while minimizing bearing friction.
- The method of suspending the unbalanced mass at both ends with pivots and jewel bearings, by using a "spider network" to by-pass the restraining torsion bar, eliminates the need for the torsion bar to act as a support and relieves it of all but tension and compression forces which it can safely absorb.

Another unique design is the pick-off which is wired with additional taps to allow a superimposed dc or ac excitation that can be filtered from the pick-off excitation. This superimposed excitation will torque the pick-off and pendulum in either direction from null providing an easy system of checking out the instrument at any time without moving the missile or aircraft.

The hermetically-sealed unit measures accelerations from ±¼g to ±50g with an accuracy (including linearity, hysteresis and repeatability under light vibration conditions) of 0.5% of full scale to half scale. Undamped natural frequency range is from 10 to 175 cps. Fairchild Controls Corp., Hicksville, N. Y.

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Aircraft cable is strung with spherical steel shells in a rigid or flexible housing sealed with "O" rings. 3" standard bend radius. ¾" minimum bend radius.

Three Types:

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3. *Extra Heavy Duty*—Compression Ult. Load 3050 lbs.; Ult. tension 3900 lbs.

Positive remote controls for actuating mechanical, hydraulic or other devices. Eliminate bell cranks, pulleys, and duct cables. U.S. Patent No. 2441719. All world rights reserved. Send for ENGINEERING MANUAL giving complete specifications covering materials, finishes, capacities. Please address Dept. EMD-PP-59.

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SERVO MOTOR	SERVO MOTOR	MOTOR GENERATOR	DC MOTOR	LINEAR TRANSFORMER	TRANSMITTER	RECEIVER	CONTROL TRANSFORMER	DIFFERENTIAL	RESOLVER
Input Power (total) 3.8 watts	Input Power (total) 1.2 watts	Generator: Input Voltage 10 v	Output Power 4.0 watts	Linearity .5%	Accuracy 7' error max.	Accuracy 30' max. error spread	Accuracy 7' error max.	Accuracy 7' error max.	Accuracy 7' error max.
Stall Torque .18 oz in min.	Stall Torque .3 oz in min.	Output Voltage .013 v/1000 rpm max.	No Load Speed 20,000 rpm	Null E at EZ .015 v	Null 30 mv max.	Torque Gradient 2700 mg-mm/deg.	Null 30 mv max.	Null 30 mv max.	Null 30 mv max.
Max. Weight 29 gms.	No Load Speed 6200 rpm min.		Input Voltage 28 v DC	Phase Shift 15 deg. lead	Phase Shift 9.5 deg. lead	Input Power .54 watts	Phase Shift 8.5 deg. lead	Phase Shift 9 deg. lead	Phase Shift 11 deg. lead

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cppc CLIFTON PRECISION PRODUCTS CO. INC.
Clifton Heights, Pennsylvania

CIRCLE 24 ON INQUIRY CARD

DIGITAL CONTROL AND STORAGE

Servo Systems Without Active Elements

A multitude of methods have been developed for creating a shaft position very accurately at a remote point as a result of some action at a transmitting point. All have a common component: an amplifier, be it vacuum tube, transistor, hydraulic or pneumatic. Using well known concepts, The Newton Co. in Manchester, Conn. has developed the necessary components to create highly precise servo systems using no active elements. The components involved are only a transmitter, a receiver (an output sensor), and a prime mover. These servo systems are adaptable to all power levels and are particularly useful where space, weight, and environmental conditions preclude the use of more conventional components without the additional complexity of compensation for changes in performance due to environmental conditions.

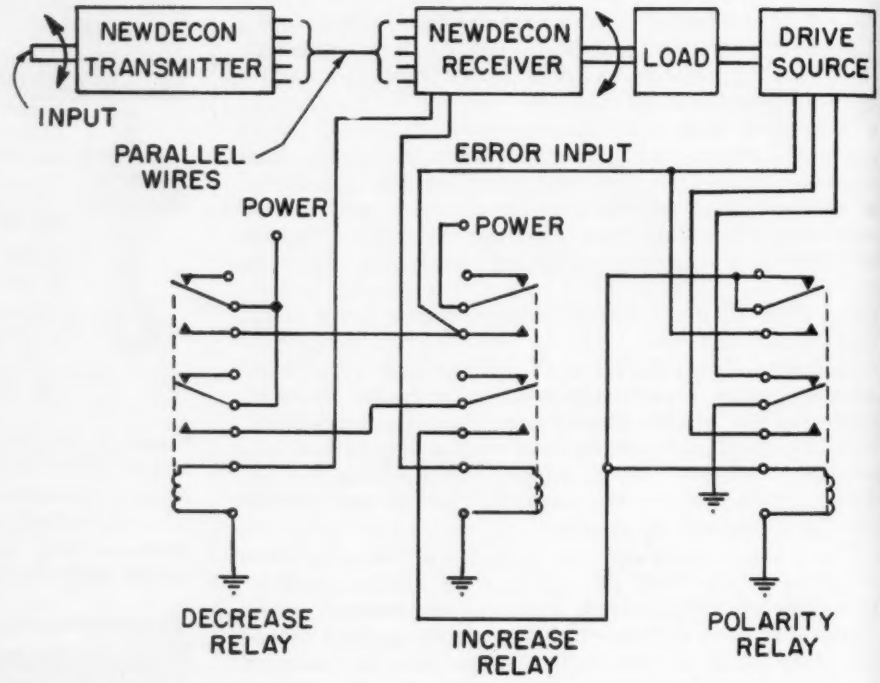

Fig. 1—Newdecon servo loop. The input is a shaft position at some remote point from the load. This shaft positions the Newdecon transmitter which is connected to the Newdecon receiver. If the shafts (input and load) are not aligned, one of two signals will be present as produced by the receiver. One of these signals will operate an "Increase" relay while the other will operate the "Decrease" relay. These relays are interlocked with a "Polarity" relay to cause the drive source to rotate in the proper direction until a null is achieved.

THE SERVO SYSTEM

To perform similar functions to those performed by synchros and potentiometers, The Newton Co. developed Newdecons. These are digital shaft sensing devices that depend on digital data rather than voltages and currents proportional to the represented quantity for activation.

Two fundamental types of Newdecons are required: transmitters and receivers. The transmitter serves as the component driven by the input command while the receiver serves as the output sensor. In combination the transmitter and receiver form a comparison device producing an error signal when the input and output do not coincide and a polarity or error signal which is used to seek the minimum path to a null.

The standard line of Newdecons are designed to operate to a resolution of 3 decimal digits or an accuracy of ±0.1%. By extending the physical size, 4 or 5 decimal digits can be accommodated thereby extending the resolution to 1 part in 10,000 or 1 part in 100,000.

Figure 1 indicated the components involved in a standard servo loop where a remote load is to be positioned directly in proportion to an input. The Newdecon receiver is wired directly to the transmitter. Number of wires required is ten times the number of decimal digits involved.

Whenever the two shafts (input and output) are not aligned, one of two signals is present from the Newdecon receiver. This signal operates either the "Increase" relay or the "Decrease" relay dependent on the short way to null. The operation of one of these two relays along with the "Polarity" relay produce an error signal to drive the prime mover to a null. The interlock circuitry involved with the "Polarity" relay is to eliminate a false 180° null commonly found in servo systems.

If positioning requirements are such that one direction only is permitted no relays are required, providing the current rating requirements of the drive source do not exceed the rating of the Newdecon.

One significant mode of operation of the Newdecon receiver is that of "servoing" to a pure decimal number rather than a shaft position. This mode of operation applies when a shaft position must be created to perform a particular function under command of a computing device whose output is a pure number. In this instance the Newdecon receiver will respond directly to the decimal number in the same way that it responds to the transmitter, requiring no active amplifier but simply the relays as indicated in Fig. 1.

An example of this would be the positioning of a machine in response to stored digital data as found in automatic machining control. The storage device could be electrical, mechanical, or electronic. The result would be a shaft position directly related to the number presented.

DIGITAL DATA STORAGE

For cases where programming is desired, a typical simplified schematic is shown in Fig. 2. The matrix arrangement is achieved by printing lines on a board in one direction on one side and lines at right angles to the first on

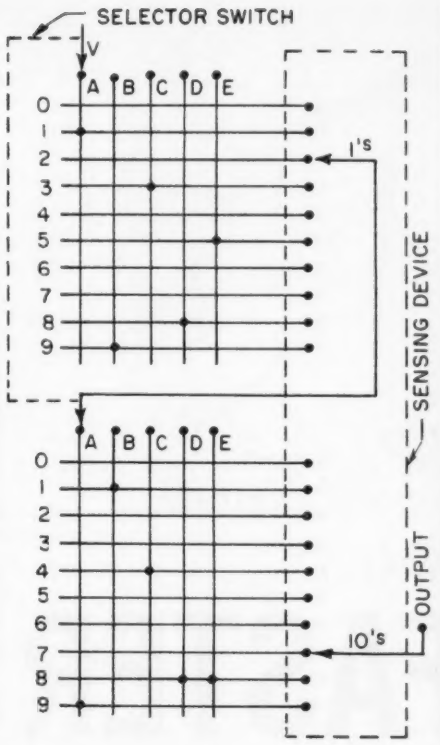

Fig. 2—Newton Co.'s method of digital storage and sensing. In this system, digital data storage is accomplished using a matrix of wires on a printed board. One dimension of the matrix is labelled A through E while the other dimension is labelled 0 through 9. A program is indicated by the numbers stored in the matrix. The dimension A through E (or more if required) is scanned as a function of some variable (time, as an example). As this dimension is scanned the sensing device (in this case a Newdecon transmitter) will have an output only when its position corresponds to the number stored in the matrix. The point labelled "Output" indicates coincidence between its position and that number stored in the matrix. At the time of this coincidence any action can be initiated by the presence of voltage (V) on the output line.

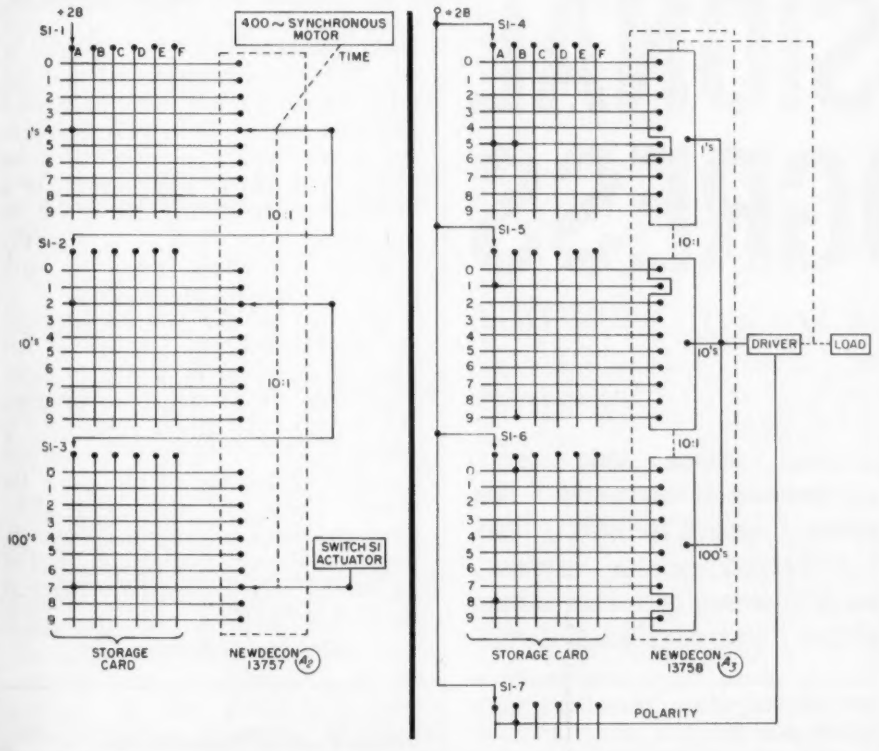

Fig. 3—Newton Co.'s method of time programming load positions by use of Newdecons and data storage cards. A time reference is provided by a 400 cycle synchronous motor. This motor drives a Newdecon transmitter which is used to sense the digital data representing time stored in the time card. Number 724 is stored in position A. Also shown is a condition of coincidence between the Newdecon sensor and the time stored. Under these conditions the Switch Actuator (S1) steps one position. In so doing, it prepares the time card for readout of the B position and presents the number stored in the B position of the load program to the output driver. This number, shown as 095, is sensed by a Newdecon receiver which causes the load to rotate until the number in the Newdecon receiver corresponds to that in the load program storage card. Also shown as part of the load program storage card is a polarity device, connected to S1-7, for choosing the shortest direction to the next null. This function is the same as that described for the servo loop.

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Designed to meet standards for guided missile systems, this new Cam Switch is typical of special designs by Tech Labs which can be easily adapted to specific needs. Write for complete data.

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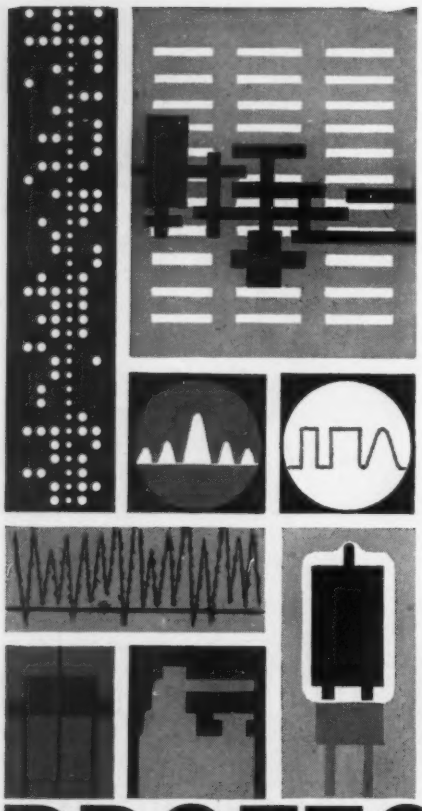

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the other side. At each intersection of lines a hole is drilled through the board. Where data is to be stored, an eyelet is inserted at the proper hole thus connecting the two lines intersecting at the point.

The Newton Co. is confident that this storage method is the ultimate in reliability. Use of eyelets makes programming of a number in the decimal system extremely simple even to the most unskilled person since the entire matrix is clearly labelled on the printed card. Testing the stored data is simply a case of checking continuity between desired points. Data stored in this manner is non-volatile and is not subject to loss due to power failure or any extraneous noise signals. Environmental conditions do not alter or hamper the operation of this data storage device and when properly plated (both card and eyelets) the shelf life applications can be almost infinite.

An example of a missile application, using Newdecons and digital storage cards, is shown in the block diagram of Fig. 3. Newton engineers say that this type of operation can easily be applied to programming a series of functions in any missile with a minimum of space and a minimum of components but a maximum of reliability. No power requirements other than those normally required in a missile system are used. No active elements are required.

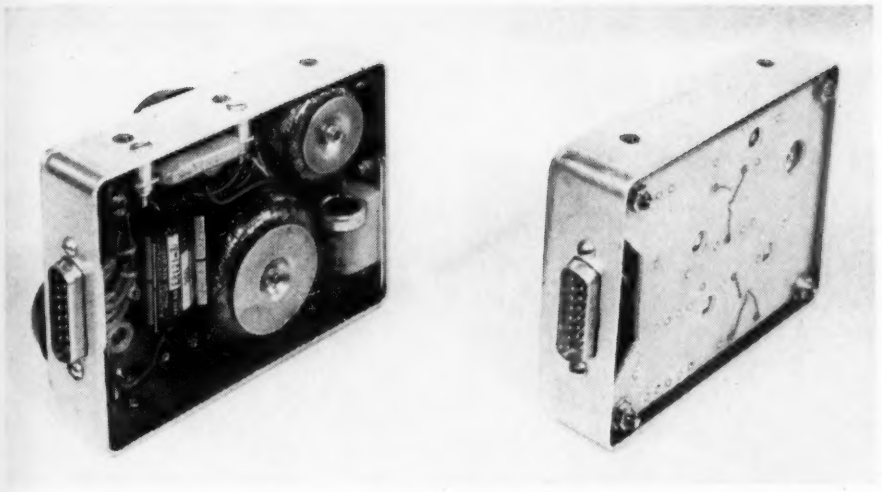
In actual use, the data storage cards can be inserted into the system just prior to launching in a plug in form. The cards are so simple to program that no ground support equipment is required. Cost of the cards is relatively low making the use of test cards for system check out entirely feasible. Since the cards are essentially two dimensional devices, they can be stacked up limited only by the space required for plug in sockets.

Circle No. 88 on Inquiry Card

Visual Control Planning Kit

A kit containing material for planning a graphic visual control has many suggestions for picturing facts graphically for production, scheduling, inventory, maintenance, sales and other applications. The kit contains: a collection of 25 tested ideas for tailoring a system to individual requirements; 24-page manual explaining the system and illustrating typical uses; a plan sheet for plotting a system on paper. Graphic Systems, New York, New York.

Circle No. 202 on Inquiry Card.



Transistorized power amplifier (at left) and transistorized pre-amplifier (at right). Note quick connect-disconnect plug connections.

MATCHED MODULAR CONTROL SYSTEMS

Packaged Control Amplifier Units Meet All Standard Operating Requirements

ANALYSIS

One long lead time item that has governed and slowed production timetables is the electromechanical control system. Since the system has had to be custom-designed and built for the specific application, its high cost, as well as delivery time, has been a continuing problem.

Attacking this problem, Airborne Accessories Corp. of Hillside, N. J. set out to develop matched modular contactorless control systems, complete from sensing device or transducer through actuator. Assembled from standardized units, these packaged systems would not only reduce design time, lead time and costs, but also facilitate field maintenance and provide increased adaptability.

Airborne Accessories had been producing linear actuators with load capacities to 500 lbs, and rotary actuators with load capacities to 100 lbs/inch, in which components were sandardized and interchangeable for flexibility. They also offered from stock a complete range of sensing devices including potentiometers, thermocouple and thermistor probes and tach generators as well as such auxiliary equipment as inverters, voltage regulators and rectifiers. But each amplifier required to complete the system had been a "special", requiring custom design and production.

The problem then, in closing the loop, was to design and build a line of "packaged" control amplifier units, each covering a range of power gain, such that they could meet all standard operating requirements.

Discussing their approach to this problem, Mr. Wolf Merel, AAC's Chief Systems Engineer, said that study of existing amplifier designs revealed every control system used several basic stages of amplification for required loop gain. These, he said, could be reduced to a small signal pre-amplifier for low level gain and a power amplifier for building up the power necessary to operate the load. Airborne Accessories made a comparative study of transistorized and magnetic equipment, using as design criteria the same basic transfer functions for transistorized and magnetic pre-amplifiers and power amplifiers. The study showed that while the transistorized pre-amplifier was lighter, amplifiers of about equal weight were required in order to reach a given power output. Although transistorized equipment appeared, as designed, to weigh less, the additional heat sinking needed to attain dissipation ratings counterbalanced this advantage.

At elevated temperatures, Merel said, magnetic amplifiers showed an advantage in stability per unit cost for amplification of d-c signals, since stable transistor amplification of carrier signals can be accomplished only when decoupled. Although it is possible to make stable transistorized amplifiers with good chopper and feedback design, costs are excessive, he said.

Airborne Accessories' engineers further observed that for powers of 100 watts output or more, controlled rectifiers provide the most satisfactory results since their efficiency permits high power output per unit weight

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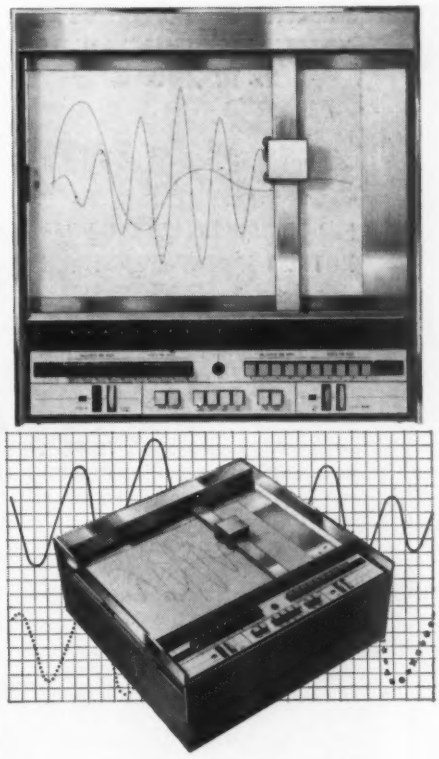

OPERATING INFORMATION

Power: 115-volt, 60 cycle—180 watts.
Input: X and Y inputs isolated from each other and from ground.
Input Resistance: 2 megohms nominal on most scales. 1 megohm per volt on .5 millivolts per inch to .1 volts per inch scales.
Input Sensitivity: .5 millivolts per inch to 50 volts per inch with calibrated push button scales at .5, .1, 5, 10 and 50 millivolts per inch and .1, .5, 1, 5 and 10 volts per inch. Vernier controls permit continuous sensitivity adjustment between fixed scales, permitting full scale plotting for any sensitivity.
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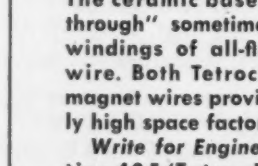

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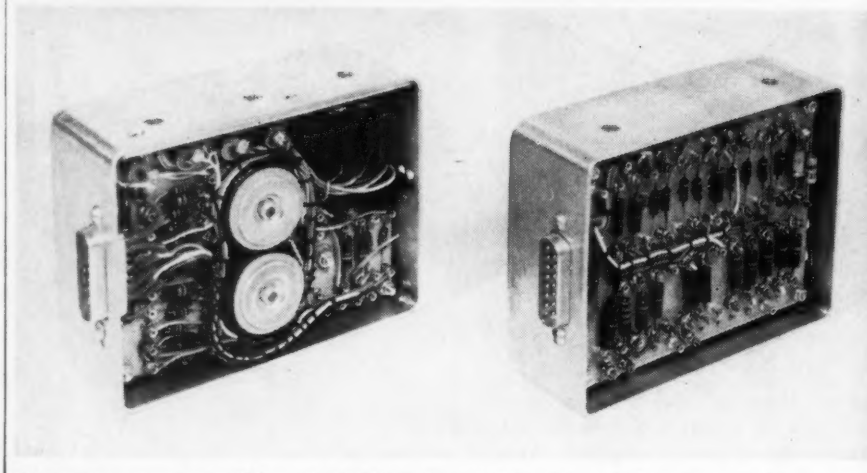
SYSTEMS DESIGN



Magnetic power amplifier (at left) and magnetic pre-amplifier (at right). Note quick connect-disconnect plug connections.

ratio. They operate best, however, Merel said, in the form of a hybrid configuration with magnetics driving the controlled rectifiers in time-displaced pulses.

These, then, were the general factors considered by Airborne Accessories in designing its modular contactorless control amplifiers.

PACKAGED AMPLIFIERS

The steady-state and derivative loop gains required for a system are generally determined by the control equipment designer. While motor performance and gear ratio to the output ram and the command transducer gain leave few variables in the loop gain, many of these are established by the amplifiers, Merel pointed out. In the Airborne Accessories' package, the amplifier is charged to provide between 10 and 60 DB of amplification for stiff loop gain performance. This is accomplished by choosing a representative pre-amplifier and coupling it to the matching power amplifier to drive the load. At present Airborne Accessories is producing two units of pre-amplification, each with a gain of about 200 volts per volt and two units of power amplification each with an approximate gain of 10 volts per volt. The combination delivers a gain in excess of 60 DB which can be attenuated to any desired value by insertion of series or shunt attentuation.

Circuitry for each contactorless control sub-system is mounted in a compact chassis and any of the units can be easily slid in or out of the control box in seconds with secure connections effected by means of a quick connec-disconnect plug.

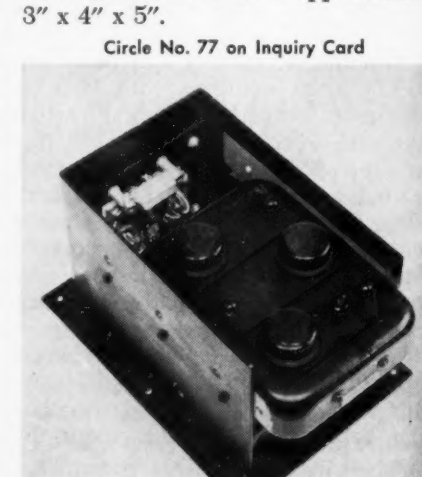
Pre-amplifiers and power amplifiers, which drive actuator motors ranging up to 200 watts, are thus designed for mounting in the same general way and, depending on the type of system required, the proper combination is programmed to cascade in the main package. Use of three input channels with the transistorized pre-amplifier enables it to be used in a control system having input command, rate and feedback loops.

Transistorized pre-amplifiers deliver about 50mw; power amplifiers 25 w continuous, with 50 w peak for lower load resistance. Magnetic pre-amplifiers deliver 8mw-18mw, and power amplifiers, 27 w DC.

Chassis operating temperature range for the transistorized pre-amplifiers is −55C to +71C with an option to 120C. Power amplifiers operate in the same range. Magnetic pre-amplifiers and amplifiers both operate at 125C.

Pre-amplifiers and amplifiers are each packaged in a 3″ x 4″ chassis and the control box itself is approximately 3″ x 4″ x 5″.

Circle No. 77 on Inquiry Card



Control box with transistorized power amplifier partially inserted. Module case (2 module stack) measures 5″x3″x4″.

Unified Vibration Systems

Unified vibration system develops 100 to 350 pounds force and operates to 10,000 cps with good waveform. Precision automatic cycling controls regulate vibration levels while sweeping frequency range of 5 to 5,000 cps with automatic transfer from displacement to acceleration. Versatility, ease of operation, reliability, interlocks and safety devices to protect personnel and equipment, make the system suitable for unattended endurance testing. Console contains controls, accessories, low voltage amplifier and adjustable field supply. The units are individually packaged for ease of servicing. Unholtz-Dickie Corp., Hamden, Conn.

Circle No. 150 on Inquiry Card

Completely Modular Scope

A new oscilloscope design features "plug-ins" for all signal generating and processing circuitry. Several plug-in systems are available to fit immediate needs yet remain fully flexible for future requirements. The main frame indicator of the oscilloscope consists of a 5-inch, single-gun cathode ray tube, its associated beam controls, identical X and Y main amplifiers, and a power supply capable of handling any present and future plug-in load requirements. Independent "slave indicator" operation is possible without plug-ins. Electronic Tube Corp., Philadelphia, Pa.

Circle No. 226 on Inquiry Card.

Film Badge Service

Commercial film badge service offers comprehensive highly specialized service containing the latest technical advances in radiation dosimetry and film-badge design: (1) The Oak Ridge system of neutron threshold foil detector can be incorporated within the badge in addition to film packets without any measurement interference. (2) Cumulative quarterly and annual data reports. (3) Microfilming of annual data reports for record safe-keeping and permanent storage. (4) Combination security - photo and film - badge single holder for neutron and beta, gamma, x film packets. (5) Extreme inherent sensitivity-less that 10 mr for hard x or gamma radiation for the total period worn—regardless of length of time up to several months; less than 5 mr for soft x or gamma radiation. (6) Ring or wrist badges are available as well as body types. Complete description of this film badge service including prices and contract schedules available. Controls for Radiation, Inc., Cambridge, Mass.

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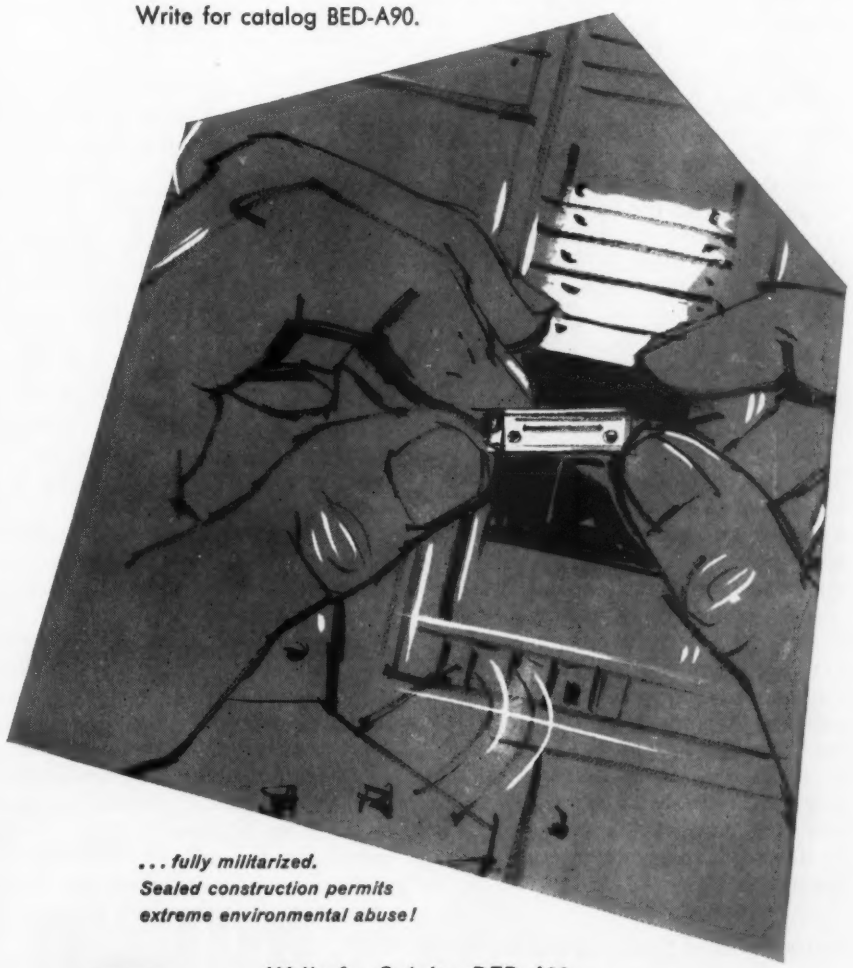

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CIRCLE 29 ON INQUIRY CARD

GAS BEARINGS FOR HIGH TEMPERATURE

Performance Predictions for 1200F Operation

Rolling-element bearings have been operated at a temperature of 1000F for a short time with special lubricants. However, expectation for successful long life operation with this type of bearing at 1000F and over is slim. Since there are indications that some bearing specifications will call for operation over a temperature range of from −65F, or even lower, up to perhaps 2000F, a formidable obstacle is presented to the development of a suitable rolling-element bearing for high temperature applications of the future.

To meet present and future high temperature bearing requirements, Analogue Controls Inc. of Mineola, N. Y. is concentrating on development of gas-lubricated bearings. Since gases, in general, are very stable over a wide temperature range and generally show a small increase in viscosity with temperature rather than a decrease, they feel that gas-lubricated bearings will greatly simplify the problems associated with high-temperature operation. The absolute viscosity of gases is very small, which means very low friction losses occur in the bearings, and much higher rotor speeds are possible without need for external cooling.

They point out that for a given load, a larger gas bearing is required than a rolling-element or liquid type bearing, unless the bearing is being used only for alignment purposes and the load-carrying capacity of the bearing is incidental. However, they say, a larger bearing is not necessarily disadvantageous because a gas bearing can be increased in size with little sacrifice in performance.

HYDRODYNAMIC OR HYDROSTATIC

In design of high temperature gas-lubricated bearings there are two types of thrust and journal bearings to be considered.

- Hydrodynamic or self-acting bearings in which the relative motion of the loaded shaft or runner in the bearing develops a geometric "wedge". Due to the viscosity of the fluid, viscous forces enable the rotating shaft or runner to "pump" fluid into this "wedge" generating fluid pressures to support the load.
- Hydrostatic or externally-pressurized bearings in which high-pressure fluid is admitted to the clearance between the shaft (or runner) and the bearing through holes or orifices in the bearing. Throttling may occur in these supply orifices or in the clearance spaces of the bearing.

With hydrodynamic bearings, a startup problem may be present. Since relative motion is required to provide a load-carrying film, metal-to-metal or solid-to-solid contact occurs at startup and at low speeds resulting in wear. At high temperatures this action becomes most serious and the choice of proper anti-galling materials is necessary. Wear at startup may be eliminated by the use of externally-pressurized bearings in which gas pressure is used to float the shaft prior to rotation.

The designer can start with external-pressurization and then cut off the gas pressure to permit hydrodynamic operation after a safe speed has been reached. Principle disadvantage of externally-pressurized bearings, both thrust and journal, is the consumption of pressurized gas. This may be held to a minimum by the proper choice of orifices, clearances and general bearing design. Some complexity of design is also entailed in ducting the gas to and from the bearing. If there are to be directional changes in the load vector, either in magnitude or direction or both, it is more advantageous to use hydrostatic bearings because they have a better load capacity for random load directions than hydrodynamic bearings.

If temperature variations and external loads are such that thermal or elastic distortion of the bearing housing occur, the bearing may be made self-aligning by incorporating some type of gimbal or flexible-diaphragm mounting. An alternate design to overcome misalignment is to use self-aligning, tilting-pad journal bearings with or without hydrostatic startup.

The various instabilities associated with journal and thrust bearings in general and with gas bearings in particular must also be taken into consideration. For example, the instability of "whirl" for journal bearings must be designed out of the bearing's operating range. This is true for hydrodynamic as well as hydrostatic journal bearings. Other performance characteristics associated with hydrostatic bearings, such as "gas-hammer" and "lockup" must also be taken into account. (Further discussion of these and other gas bearing phenoma is given in A. S. M. E. Paper No. 58-A-

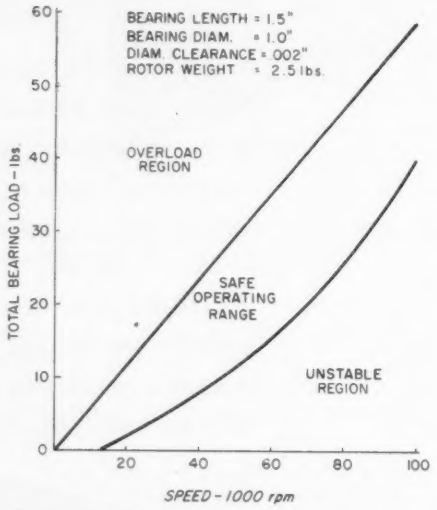

Fig. 1—Hydrodynamic bearing load vs speed for 1200F operation.

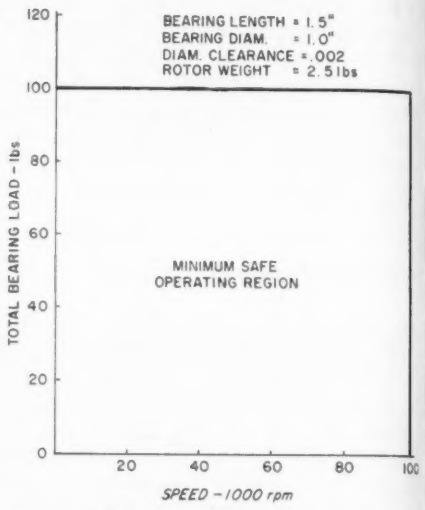

Fig. 2—Hydrostatic bearing load vs speed for 1200F operation.

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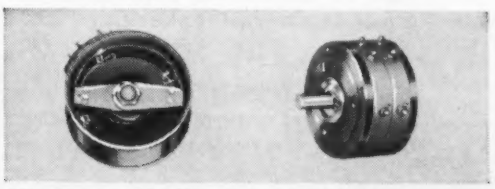

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CIRCLE 32 ON INQUIRY CARD

231 "Some Instabilities and Operating Characteristics of High-Speed Gas Lubricated Journal Bearings"—Fischer, Cherubim, and Fuller.)

As a result of approximately four years of intensive work in this field, Analogue Controls has developed the design capability to predict performance of several types of bearings with reasonable accuracy prior to their operation.

PERFORMANCE FOR TYPICAL REQUIREMENTS

To give some idea of the size of a a gas bearing that might be required and its expected performance, a preliminary design of a bearing is presented for what might be a typical set of requirements.

1. The working fluid or lubricant is air at 1200F.
2. External load at startup is only rotor weight and load is applied as a direct function of speed until a maximum total load of 50 lbs is on the bearing.
3. No thrust loads are present.
4. The rotor weighs 2.5 lbs.
5. The maximum speed at 50 lbs load is 100,000 rpm.
6. Ambient pressure is atmospheric pressure at sea level.
7. Load is undirectional.

Analogue has calculated for us the performance for these requirements of a bearing 1.0" in diameter, 1.5" long with a diametrical clearance of 0.002". If this bearing operated hydrodynamically, the load-speed performance shown in Fig. 1, would be obtained. The upper line is the maximum load at any speed that could be applied to the bearing and still maintain a minimum film thickness of 0.0002" between the shaft and the bearing. This value is not arbitrarily selected but is based on experience and includes allowances for normal machining, cocking, distortion and other factors that might tend to rupture the load-carrying film. The lower boundary is the maximum speed that can be run for a given load before the journal becomes unstable due to half-frequency whirl. Operation in the unstable region at high-speed will almost inevitably lead to failure. The area between the bounding curves then represents the safe operating range at 1200F. Also, it is seen that if the unit is started up with only the 2.5 lbs rotor weight on the bearing, metal-to-metal contact will occur until a speed of about 4000 rpm is reached and then a load-carrying film will develop. The rotor may then be run up to about 20,000 rpm. This speed can not be exceeded without "whirl" taking place, until more load is placed on the shaft or bearing.

If it is required that the rotor be started under 50 lbs. load, high temperature materials must be used such as Monel 5, Alumina, or Inconel to withstand such a large galling load for this size bearing. However, it may be desirable to use a hydrostatic start. If pressure of say 300 psia is available to the bearings, orifices could be drilled in the bearings say 0.005" in diameter. In such a case the full 50 lbs could be supported hydrostatically at the start. In fact, if hydrostatic air is always available and pressurization occurs continuously, the performance shown in Fig. 2 could be obtained. Apparently a much greater effective operating range is obtained with the hydrostatic design.

On the other hand if no gas pressure is available and the requirement is to run with only rotor load to 100,000 rpm and then apply a total load of 50 lbs, it would be necessary to use tilting-pad journal bearings. The reason is that tilting-pad bearings are more stable when lightly loaded than are plain or grooved journal bearings. The instability of whirl would certainly cause failure before 100,000 rpm could be reached if the above bearing were operated purely hydrodynamically with a rotor weight of only 2.5 lbs and no other external load. If a low maximum operating speed is required to support the 50 lbs load, a large bearing would be necessary and/or smaller clearance. For example, a bearing 2" long and 2" in diameter with a diametral clearance of 0.002" would run safely with a 5 lb rotor at 50,000 rpm and applied loads ranging from 40 to 150 lbs.

Although the bearings discussed in this section are capable of meeting the assumed conditions, it does not necessarily mean that they are the only ones that can be used. However, they are typical of the approximate sizes that would be expected. Diameters, lengths and clearances, orifice sizes and distributions can be varied to give a suitable configuration for use and manufacture.

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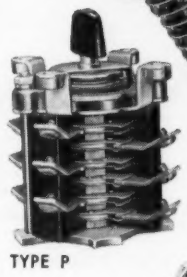
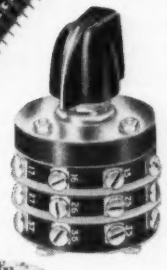
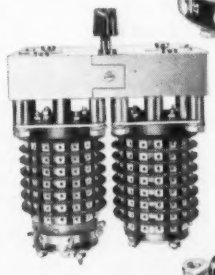


TYPE P

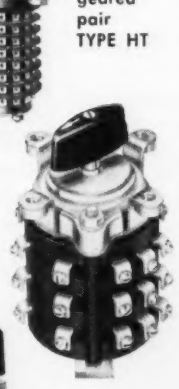
gear-operated TYPE JR



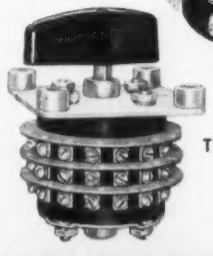
TYPE A/AF



geared pair TYPE HT



TYPE JS-JD



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CIRCLE 33 ON INQUIRY CARD

DESIGN TIME SAVER

Lawrence A. Gregory
Magnetic Controls Company
Minneapolis, Minnesota

ANALOG COMPUTER DESIGN OF MAGNETIC AMPLIFIERS

Regardless of the mathematical approach used in the design of magnetic amplifiers, the multiple solution of several equations, some of which have nonlinear variables, is the cause of considerable time loss and error. Here are fundamental techniques in the analogical solution of such equations that minimize time and error. Simultaneous solution of several equations involving common variables can be more quickly accomplished by substituting variable voltages as the counterpart of mathematical variables in these equations. The combination of these voltages according to mathematical rules can be read or recorded on any electrical measuring device and transformed back into original mathematical language to attain the desired design data.

Numerous mathematical approaches to the design of a magnetic amplifier exist but, regardless of approach, the final design must conform to two physical conditions: the number of turns of the particular wire size indicated by the design must fit within the selected core; and the temperature rise of the final reactor must be within allowable limits.

With a set of magnetic amplifier specifications at hand, the designer generally follows a design procedure as follows:

- He selects a particular core which he "feels" will fulfill the specs.
- He then solves the voltage absorption, time constant, and gain equations.
- Solution of the volumetric equations determines whether or not the wire size previously calculated fits into the core selected. If it does, he then must solve the thermodynamic equation of the reactor to see if temperature rise is within specs. If either of the last two conditions are not satisfied, the reactor is impractical. He then must select another core and continue the same process until the designed reactor conforms to all specs.

Such a procedure is extremely time consuming and the chances for error are great since there are several equations involved in the solution. We wish, then, to propose the use of an analog computer to solve the various equations simultaneously thereby greatly reducing the design time and minimizing the possibility of "human error". Most engineers do not consider analog computers for the solution of algebraic equations but think of the analog computer only as a means of solving equations with time as the independent variable. However, since the analog computer performs the four basic arithmetic functions—division, multiplication, addition, and subtraction—it seems quite logical that the computer should be used for this particular purpose.

The solution of this problem by analog computer does not eliminate any of the steps involved in the design of a magnetic amplifier. It does, however, increase the speed of computation of these steps, because the solution of a particular equation as a result of a change of a variable can be obtained as fast as the variable can be changed. Flexibility of design is also increased because of the relative ease of simulating nonlinear functions with an analog computer, whereas in hand calculations of magnetic amplifier design, the tendency is to "linearize" these nonlinear functions to simplify their solution.

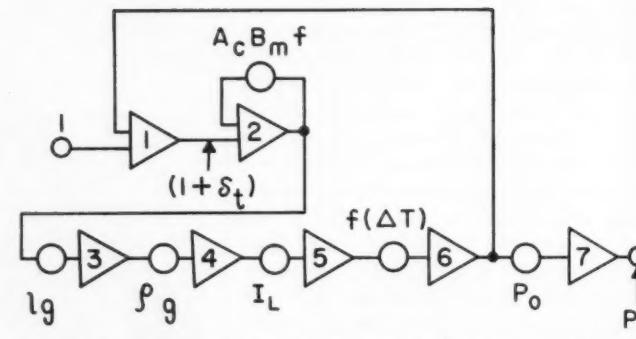

Fig. 1—Basic analog block diagram of the power dissipation equation of a magnetic amp'ifier reactor.

BASIC EQUATIONS AND BLOCK DIAGRAM

Since each type of magnetic amplifier circuitry requires a different mathematical approach, we will use the full-wave doubler circuitry as a design vehicle. Factors effecting the power dissipated in a reactor of this type at full power output are indicated in (1).

$$(1)\quad P_r = 0.5\, I_L{}^2[l_g\rho_g(0.9E_o[1+S_t]/4B_M f A_c \times 10^{-8})(1+[T_1-T_o+\Delta T]\alpha_o)]$$

$$(2)\quad P_x = 0.5\, I^2\, R_x = 0.5\, I^2\, l_x\, \rho_x\, N_x$$

The term within the large bracket represents the resistance of the gate winding in a reactor of the same form as (2); and, the terms in the first inner bracket represent the number of gate-winding turns as a function of core parameters, output voltage, and applied frequency. If we assume a purely resistive load, such that the output power is represented by the product of the line current and the output voltage, Fig. 1 then represents the analog block diagram of the preceding equation where

$$(3)\quad f(\Delta T) \stackrel{\Delta}{=} 1 + (T_1 - T_o + \Delta T)\alpha_o$$

A simple relationship, involving an empirical coefficient and the reactor surface area, equates the temperature rise of the reactor to the power dissipated in the reactor. Core

losses are assumed negligible by designing for maximum output conditions where the cores are saturated for the entire cycle of line frequency.

$$P_r = \Delta T\, S_r\, c \tag{4}$$

The substitution of (4) in (1), and the solution for ΔT by analog computer methods, results in a cumbersome, complicated array of amplifiers and potentiometers. A more simple and convenient method is to set each of these equations in the computer individually and to solve them simultaneously. Fig. 2 indicates this method.

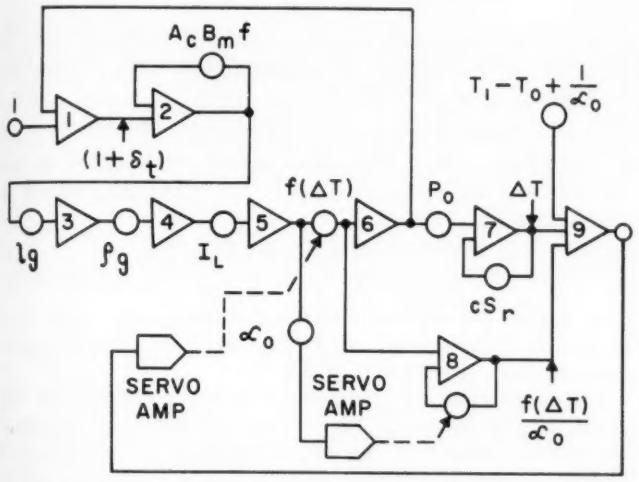

Fig. 2—Analog block diagram of the simultaneous solution of the power dissipation and temperature rise equations of a magnetic amplifier reactor.

Note that the output of amplifier 7 is now equivalent to the temperature rise because of the division of P_r by the product $c\,S_r$. If the output of amplifier 5 is 'A', the output of amplifier 8 is equivalent to $'A'f(\Delta T)/'A'\alpha_0$.

Adjustment of $f(\Delta T)$ for zero output from amplifier 9 thereby equates the temperature rise in (1) to the temperature rise in (4), thus assuring the proper setting of the $f(\Delta T)$ potentiometer for the specific values of mean-turn length, l_g, gate-winding resistivity, ρ_g, and dissipating surface area, S_r.

ANALOG DEVELOPMENT OF PHYSICAL CHARACTERISTICS

Since the basic equations and the block diagram do not take into account the methods necessary to establish the values of mean-turn length, resistivity, and core-dissipation area, we must develop these quantities analogically as functions of the physical dimensions of the selected cores. Simple relationships with empirical coefficients will be used for the sake of clarity and ease of understanding. The mean-turn length is a function of the perimeter of the core cross section as indicated in (5).

$$l_g = \delta_L(d_{oc} - d_{ic} + 2\,h) \tag{5}$$

If we assume the surface area of the finished reactor to be cylindrical, and also assume common control winding techniques, then

$$S_r = 2\,\pi\, d_{oc}(d_{oc}/4 + h)\delta_r \tag{6}$$

The development of the gate-winding-resistivity equation is not as straightforward, however, since it is a function of the amount of wire that can be wound into the inside diameter of a particular core with a particular toroidal-winding machine. If we allow a practical ratio of the inside diameter of a wound reactor to the inside di-

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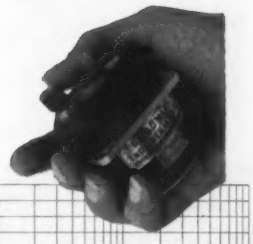
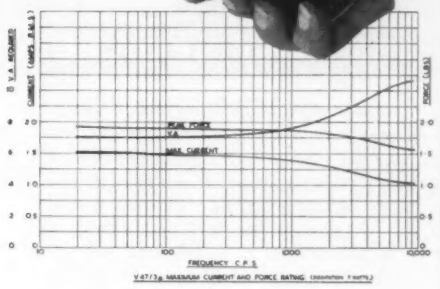
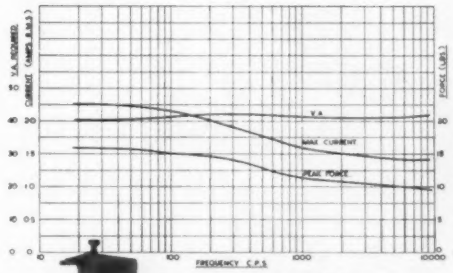


MINIATURE
MODEL V47
Weight: 2 lbs.

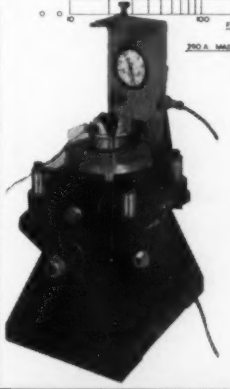


SPECIFICATIONS	V47	390A
Maximum Frequency	10 kc/s	4 kc/s
Mass of Moving System	6.5 gm	0.16 lb.
Static Force Factor (lb/A)	0.9	5.0
Maximum Continuous rms Current at 500 cy. (Uncooled)	1.5A	1.75A
(Air-Cooled)		3.50A
D.C. Resistance (Ohms)	2.5	6.4



GENERAL-PURPOSE MODEL 390A

Shown being used to calibrate a seismic pick-up.



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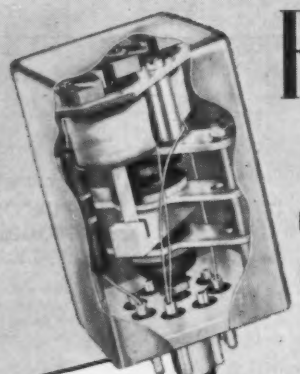

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ameter of the core, S_h, and combine this relationship with (7) and (8),

$$d_{ir} = 2\,[(\pi\, d_{ic}^2/[4 + \delta_{wi}\, A_w])/\pi]^{1/2} \tag{7}$$

$$A_w = N_g A_{wg} + N_c A_{wc} + N_b A_{wb} + \dots \tag{8}$$

the turn-area equation, (9), results.

$$N_g A_{wg} + N_c A_{wc} + N_b A_{wb} + \dots = \pi\, d_{ic}^2 (1 + \delta_h^2)/4\,\delta_{wi} \tag{9}$$

The interrelationship of wire resistivity and area can be determined by plotting each against wire size, as in Fig. 3. The resulting relationship.

$$A_{wx} = 15.53 \times 10^{-6}/\rho^{0.9524}\ \text{Square Inches} \tag{10}$$

in combination with (9) gives us the relationship of the resistivity of the gate winding to the other parameters in the reactor:

$$\rho_g^{0.9524} = [247\, E_o(1 + \delta_t)/B_m\, f\, A_c]/[\pi\, d_{ic}^2(1 + \delta_h^2)/(4\,\delta_{wi} - N_c A_{wc} - N_b A_{wb})] \tag{11}$$

The analog development of the resistivity, the mean-turn length, and the surface dissipating area in block-diagrammatical form, is indicated in Fig. 4.

Let us momentarily review the design procedure to this point. Fig. 1 is the analog solution of the basic equation for reactor power dissipation. Expansion of this diagram to Fig. 2 gives rise to the solution for temperature rise in terms of three unknown parameters: dissipating-surface area, gate-winding wire resistivity and mean-turn length. Advancing to Fig. 4, we develop the three unknowns in terms of turn-area products of the control, bias, and other supplementary windings.

It is the method for the development of the control turn-area product which is the most controversial in the design of magnetic amplifiers. So, to forestall any disagreement with our particular choice, we must again say at this point that we are attempting to show only analogical

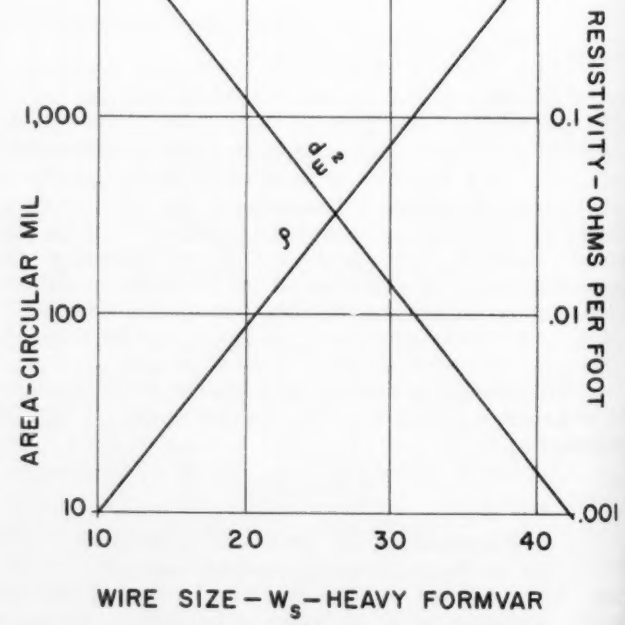

Fig. 3—Variation of resistivity and circular mil area with wire size for heavy formvar insulated copper magnet wire

procedures for the solution of a particular mathematical design method. With this idea clearly in mind, we will continue and develop the control turn-area product as a function of the data obtained on the DC reset tester as recommended by the AIEE Magnetic Amplifier Committee. Figure 5 indicates the relationship from which (12) is derived.

$$N_c = 3\,H_r\,l_m\,\delta_{RS}/0.4\,\pi\,\Delta I_c \tag{12}$$

and establishes the controls turns as a function of the core 'gain' and the desired differential control current from the original reactor specifications. The dimensionless coefficient, δ_{RS}, is included to equate the sine-current gain, as indicated by the DC reset tester, to the sine-flux gain which would be the actual reactor gain. Combining (10), (12) and the general winding-resistance equation, (2), we arrive at the turn-area-product equation for the control winding:

$$N_c\,A_{wc} = (2.39\,l_m\,H_r\,\delta_{RS}/\Delta I_c)^{1.9524} \times (8.93 \times 10^{-6}\,l_c/R_c)^{0.9524} \tag{13}$$

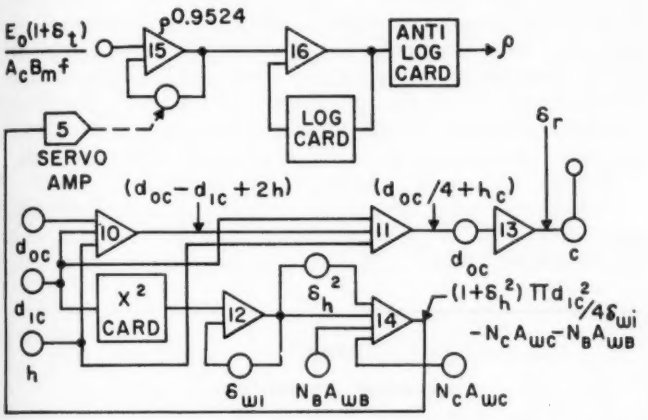

Fig. 4—Ana'og block diagram of the gate winding resistivity, the winding mean turn length, and the surface dissipating area equations of a magnetic amplifier reactor.

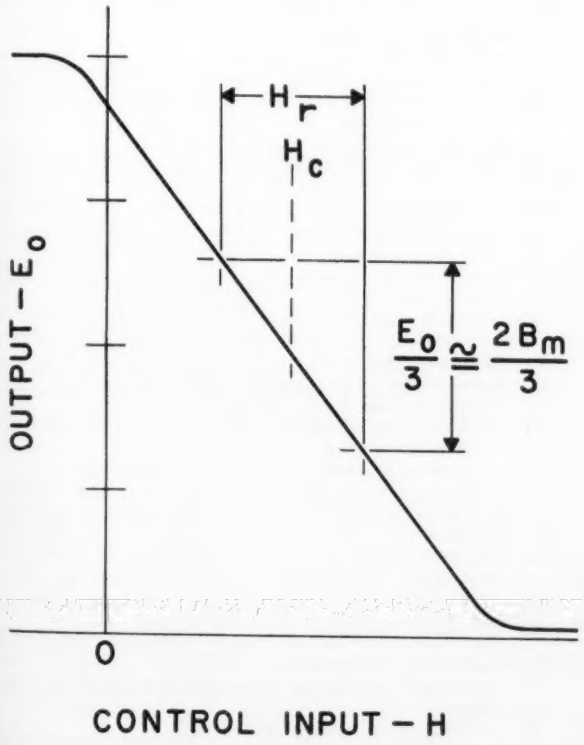

Fig. 5—Typical magnetic amplifier transfer curve.

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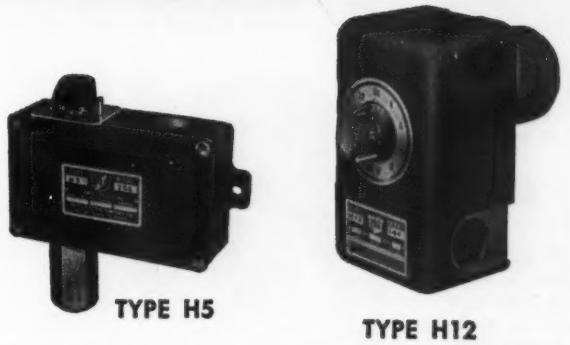

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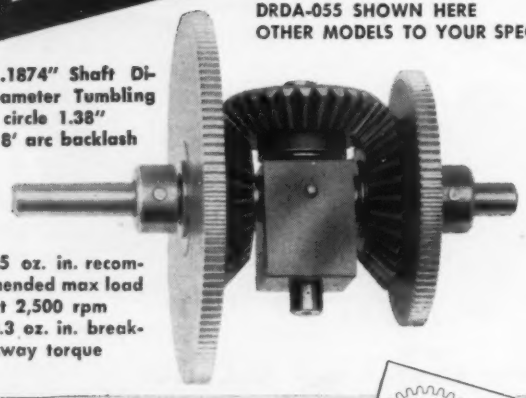

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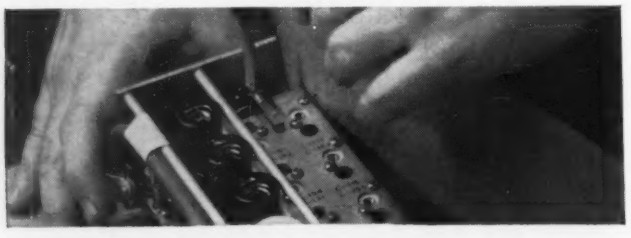

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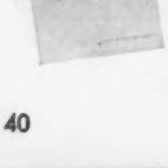

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Since our primary aim is one of didacticism, we will neglect all but the gate and control windings and form a composite block diagram of the entire magnetic amplifier reactor design as in Fig. 6.

At first glance, Fig. 6 appears to be a formidable array of amplifiers, potentiometers and function generators, and might well raise the question: "Are we really saving time in utilizing the analog method?" Most designers actually perform each of these steps whether realizing it or not, while designing a magnetic amplifier. Of course, some of these steps are done by "intuition" or "feel". In choosing a particular number of control turns for a magnetic amplifier, a designer might arbitrarily choose a thousand turns of No. 33 wire because by past experience he knows it will give him a suitable gain and time-constant characteristic for the particular core. Granted, to set up such a block diagram on a computer requires a certain amount of time, but, once having set it up, a designer may complete several designs in a very short time and this procedure eliminates much of the guesswork normally involved in magnetic amplifier design. Of course, in the cases where empirical coefficients are used, the more accurate these coefficients—the more accurate the final result.

The method used here has a certain amount of crudity associated with it; but more sophisticated methods can be developed, taking into account more variables. For

TABLE I

Symbol Definitions

A_c	=	effective core cross sectional area
A_w	=	total core winding cross sectional area
A_{wb}	=	bias winding single wire cross sectional area
A_{we}	=	control winding single wire cross sectional area
A_{wx}	=	X_{th} winding single wire cross sectional area
B_m	=	maximum core flux density
c	=	temp. coefficient of power dissipation—watts/degree/unit area
d_{ic}	=	inside diameter—toroidal core case
d_{ir}	=	inside diameter—wound reactor
d_{oc}	=	outside diameter—toroidal core case
E_o	=	magnetic amplifier maximum output voltage—rms
f	=	line frequency—cps
h	=	height of toroidal core case
H_r	=	differential magnetic intensity necessary to obtain output change from $2E_o/3$ to $E_o/3$
I_L	=	line current—full load—rms
l_e	=	mean turn length—control winding
l_g	=	mean turn length—gate winding
l_m	=	mean path length—core flux
N_b	=	bias winding turns
N_e	=	control winding turns
N_g	=	gate winding turns
P_o	=	maximum output power
P_r	=	power dissipated by magnetic amplifier reactor
P_x	=	power dissipated by X_{th} winding
S_r	=	reactor heat dissipating surface
T_1	=	ambient temperature
T_o	=	temperature at which initial resistance is measured
α_o	=	temperature coefficient of resistivity—ohms/ohm/degree
ΔI_c	=	differential control current for minimum to max. output voltage
ΔT	=	temperature rise
δ_h	=	ratio d_{ir}/d_{ic}
δ_L	=	ratio—mean length of turn/core cross section perimeter
δ_{RS}	=	ratio—sine flux core gain/sine current core gain
δ_r	=	ratio—actual surface area/equiv. cylindrical surface area
δ_t	=	regulation—decimal form
δ_{wi}	=	ratio—area of winding displacement/area of winding copper
ρ_g	=	resistivity—gate winding copper
ρ_e	=	resistivity—control winding copper

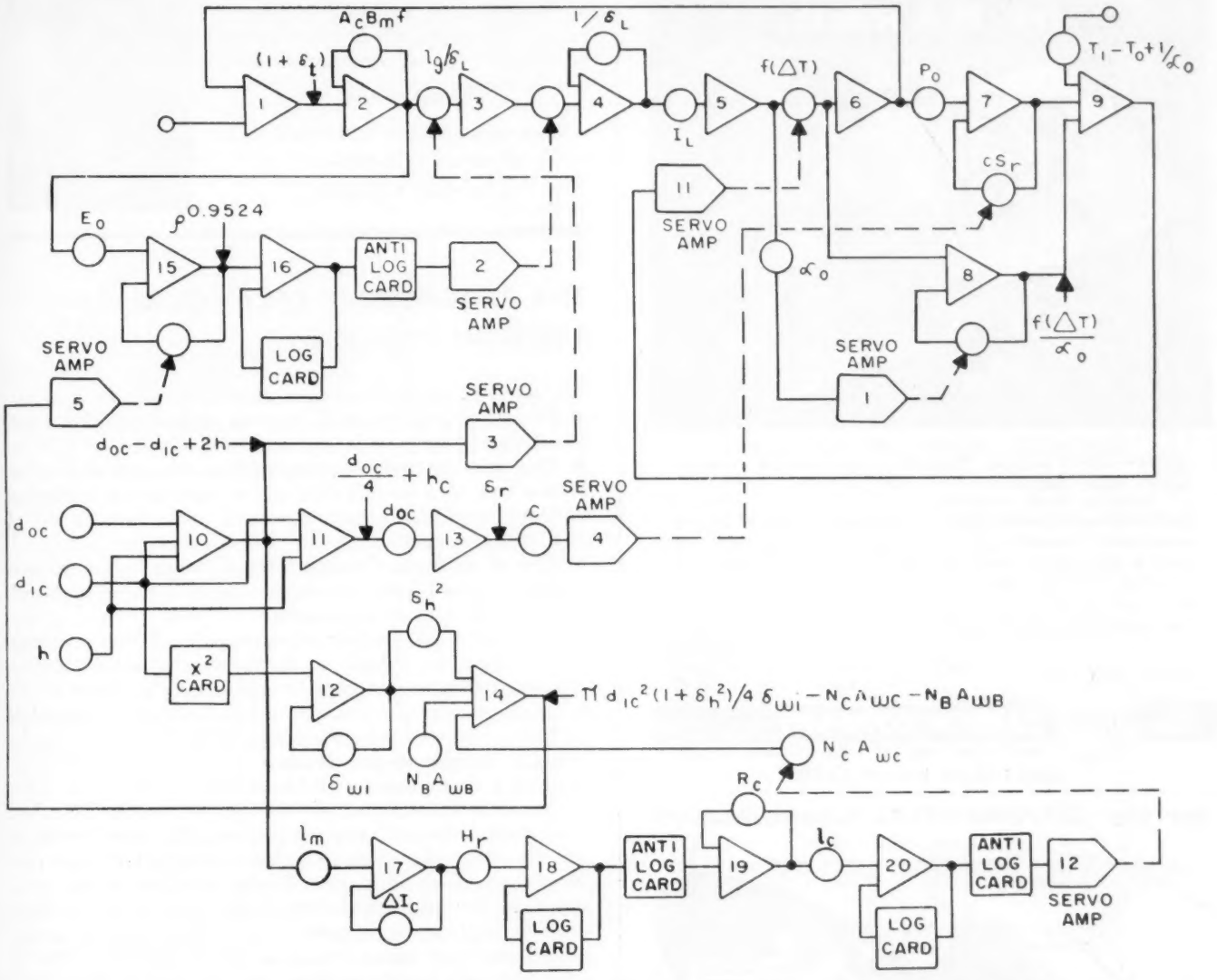

Fig. 6—Complete analog block diagram of design equations for a magnetic amplifier reactor.

example, you can develop the partial differential-thermal equation and solve for the power-dissipation constant, c. Whatever is done, each step is merely an expansion of the basic equation, (1).

Fig. 6 is made even more complicated by the inclusion of the several servo amplifiers. However, since most small analog computer installations do not have a multitude of servo amplifiers available, the null method may be used to set the servo-driven potentiometers.

To be specific, let us go through a design procedure without utilizing the automatic features of the servo amplifiers:

1. Set the potentiometer representing all known parameters, such as P_O, I_L, etc., by adjusting the position nf the pot at a percentage of its total travel equal to the ratio of the known value of the parameter to the maximum value of the parameter represented by each potentiometer on the block diagram (e.g. a desired power output of 40 watts would require a pot setting of 40 per cent of its total travel if the maximum power output, as indicated at the potentiometer, were equal to 100 watts).

2. After selecting a particular core, set the core-dimension potentiometers, d_{oc}, d_{ic}, l_m, and the core 'gain' potentiometer, H_r.

3. Null the division-potentiometer of amplifier 15 with the output of amplifier 14 and null the gate-winding-resistivity potentiometer with the output of amplifier 16.

4. Null the mean-turn-length potentiometer, l_g/δ_l, with the output of amplifier 10.

5. Null the division-potentiometer of amplifier 7 with the output of the power-dissipation-coefficient potentiometer in the output of amplifier 13.

6. Null the division-potentiometer of amplifier 8 with the output of the α_o potentiometer.

7. Adjust the $f(\Delta T)$ potentiometer until the output of amplifier 9 is zero. *(NOTE: Since the output of amplifier 5 is dependent upon the output of amplifier 6, step 5 and step 6 above may have to be repeated two or three times in order to assure an absolute null of amplifier 9. Utilizing the servo amplifier, this nulling procedure would be done automatically. Therefore, only one setting of the function of T potentiometer would be necessary.)*

8. The regulation, δ_t, and the temperature rise, ΔT, can now be read directly at the output of amplifier 6 and amplifier 7 respectively.

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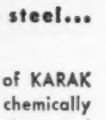

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THE PROGRESSIVE RECIPROCAL REVISION PROCESS

We noted in previous columns that:

- Inventing is the mental function of forming idea combinations or "compounds" out of idea elements:
- One may start with a group of idea elements and try to form a new idea combination out of them or one may start with a known idea combination and try to form it out of new idea elements;
- One of the basic characteristics of the invention process is that the mind forms new idea combinations by trial-and-error matching of idea elements.

Recognition of another characteristic of the invention process may be helpful in developing inventive ability: this characteristic may best be called the "progressive, reciprocal" revision process. The mind does not invent solely by fitting idea elements to a desired idea combination or by working entirely in the direction of fitting idea combinations to a desired group of idea elements. Rather it shifts back and forth from one of these procedures to the other. This shifting to-and-fro is not random. The mind works in one direction as far as it can and then uses that advance as a basis from which to make a further advance in the other direction. For instance, the mind may start on an invention problem with a rough guess at the idea combination required, and may arrive at a group of idea elements that fit tolerably well to this pattern. The mind may then scrap the combination pattern it started with and attempt (by trial-and error) to get a combination pattern which fits closer to this new group of idea elements. When it has found a closer-fitting combination pattern, the mind may select, again by trial-and-error, other idea elements which fit even more closely to this new combination pattern. Thus a reciprocal revision of idea elements and idea combinations takes place and moves the problem solution progressively forward until the ultimate solution is reached. A good example of this process is a solution to the following practical invention problem.

Example—Progressive Revision Process. Consider the problem of moisture content in newsprint. It is well known that if newsprint has more than 8% moisture, it blots the ink when going through the high-speed press. But should the paper be dried so much that it has less than 6% moisture, it will tear frequently in going through high-speed presses. The natural reaction to this problem is: "Let's control the drier in the paper manufacturing machine so the paper comes out with only 7% moisture—just the ideal condition, midway between the hazard of frequent press shutdown due to tearing and the menace of irate subscribers when their newspapers look like smudged blotting paper." Many a gimmick has been devised to control the moisture in newsprint as it is being manufactured. But, this solution overlooks a principal of inventing pointed out in last month's column on the "Technique of Originality": beware of taking things

for granted. This first solution takes for granted that we must control the moisture content of the paper.

Having detected what we've been taking for granted we challenge it. *"Is it essential to produce newsprint of just this exact moisture content? Couldn't we let the newsprint come off the paper machine at whatever moisture content is most practical and then adjust the tension on the sheet as it goes through the high-speed presses so it will not tear? Or maybe we could adjust the ink flow so that the paper would not blot? Perhaps we could avoid both these things by locating a heater at the press to dry the paper to just the right value of moisture content to prevent both blotting and tearing?*

With radioactive isotopes to send gamma rays through the paper, and by measuring how much of the rays get through to the other side, we could accurately measure the moisture content of the newsprint as it moves along at high speed. Hence we could hook up the moisture content meter to change the tension, vary the ink flow, or control the heating.

Being up-to-date inventors, we know about dielectric heating by radio-frequency currents and we recall that the amount of energy absorbed, hence the amount of heating, depends on the degree of conductivity of the material being heated. Now, as the moisture content of paper increases, it makes the paper more conductive. What could be better, then, than to heat the paper as it feeds into the press and to use dielectric heating with radio frequency currents? We then will not have to do any very difficult regulation of the heating, because the degree of heating will regulate itself. The drier the paper, the less conductive it is, the less RF energy it absorbs and the less it is heated and dried. It looks good, so at this point we experiment to see how well paper can be dried by dielectric heating. The questions we want answered are:

1. Is enough heating possible by high frequency dielectric heating in a poor conductor like moist paper to bring the paper quickly to the required moisture content?

2. What will the dielectric heating cost?

We find that the heating can be made adequate, but at a relatively high cost; so we consider the idea element of using gas to accomplish the heating. But then we find that gas heat produces great and rapid changes in the tension of the sheet. So we shift back from the idea combination of heating the paper in the press to that of tension control to prevent tearing or blotting of the newsprint. And we find that the idea element for accomplishing this tension control is slight heating with a gas heating unit. From here to the complete solution of the problem is not very far. The tension of the sheet of newsprint can easily be made to move a valve which controls the flow of gas to the heater; and automatic control to prevent trouble from newsprint as it goes through a high-speed press is complete, regardless of wide variations in the moisture content.

We started with one idea combination—using the paper's conductivity to regulate its moisture content; but in searching for the right idea element to effect the heating, we found that a different idea combination—the control of tension—solved the problem better.

In most inventions you will find this process of shifting back and forth between fitting idea elements to a combination, or fitting combinations to a group of idea elements, has to be done, and often it has to be done several times before the problem is solved. Experimentation will often indicate when to shift from one of these directions to the other, and what idea elements or combinations to shift to.

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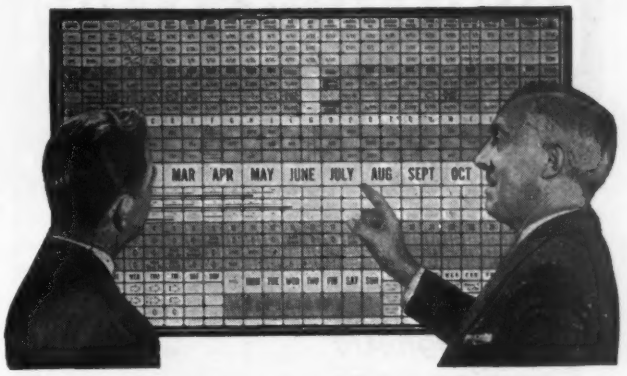

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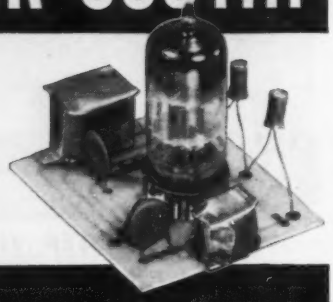

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Thermocouples And Assemblies

50 page catalog offers complete information on a full line of thermocouples and thermocouple components and accessories. This manual describes specialized thermocouples and assemblies for laboratory and industrial applications; and an extensive line of bare and insulated thermocouple wires, replacement elements, ceramic insulators, metal and ceramic protecting tubes, wells, terminal heads and extension leadwires. Recommendations are given on the choice and use of thermocouples and assemblies and on the limitations of protecting tube and well materials.

Source: Leeds & Northrup Co.
Philadelphia, Pa.
For your copy: Circle No. 224 on Inquiry Card

Platinum-Group Metals

Eight-page general brochure, describes the platinum-metal products including solid and clad platinum metals and alloys in sheet, strip, wire, foil and seamless tubing; parts, shapes and specialties; electrical contacts, electrodes, gauze, catalysts, salts and derivitives, expanded anodes, laboratory ware, rhodium plating solutions, transistor materials and thermocouple wire.

Source: Metals & Controls,
Attleboro, Mass.
For your copy: Circle No. 138 on Inquiry Card.

Application Notes on LDT's

Eight-page bulletin presents condensed semi-technical notes on basic design of control systems using linear differential transformers as a-c transducers with a-c or d-c outputs. Topics covered include simple circuits, mountings, shielding, etc. A price and specification sheet is included.

Source: Minatron Corp.
Belle Mead, New Jersey
For your copy: Circle No. 156 on Inquiry Card

Through Haydon Research...

BETTER ANSWERS TO YOUR TIMING PROBLEMS TODAY *and* TOMORROW!

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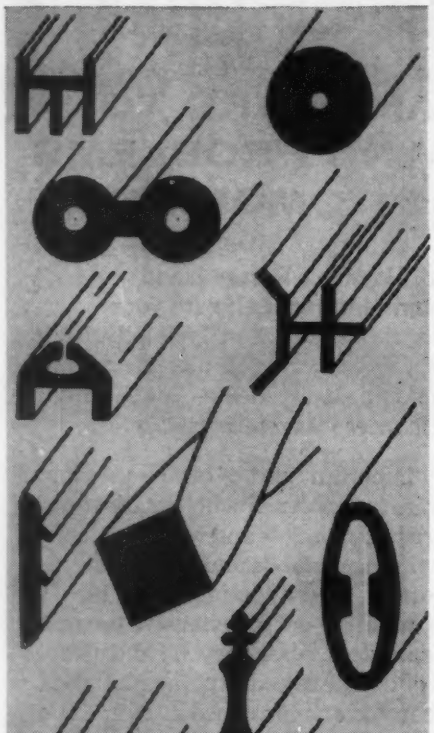

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New Electromechanical Components For Electromechanical Systems

Circuitizers

Two fully automatic circuit tester analyzers are designed to check up to 52 circuits for high potential breakdown, correctness of wiring through continuity and (100 megohms) insulation resistance of cable and harness assemblies. They use quick disconnect terminal boards to permit rapid adaptation of testers to specific hookups and allow for standard 19-inch relay rack mountings, or may be installed in a case for bench top operation. The circuit selector pinpoints the fault enabling the operator to continue testing the remaining wires by actuating the fault override switch. Guardian Electric Mfg. Co., Chicago, Ill.

Circle No. 140 on Inquiry Card

Distance Detector

A precision electromechanical transducer generates an output voltage as a function of distance. A high sensitivity gradient and a fast response make it a particularly precise and versatile unit. The distance detector consists of a control unit and a sensor. The control unit contains the circuitry for detection; the sensor contains the pickoff element from which distance is measured. The pickoff element is a pancake-wound coil which may be loaded by the presence of an external shorted secondary coil. Design of the pickoff element virtually eliminates inputs from directions perpendicular to the sensitive axis. Use of transistors throughout the control unit results in optimum operation with low power consumption. Bently Scientific Company, Berkeley, Cal.

Circle No. 135 on Inquiry Card.

Miniature Potentiometer

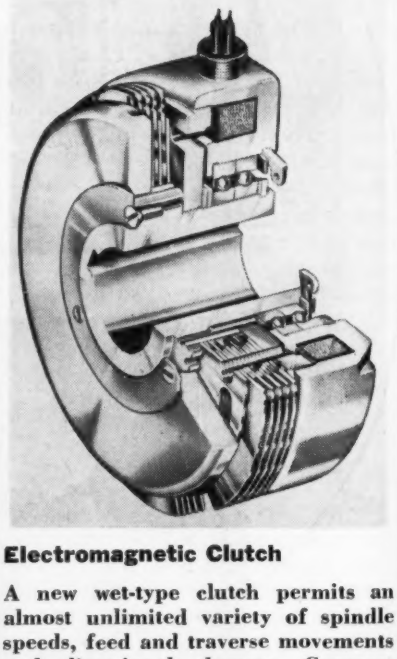
A precision wound, ¾" diameter, round pot using an all aluminum housing for lightness, is gangable, three to a common shaft. Other specifications: diameter—¾-inch; thickness—.350" from mounting surface; weight—12 grams; power rating—1.5 watts at 25C; electrical rotation—359° or supplied with stop to limit travel; terminals—silver plated for easy soldering; slip ring & brush—precious metal; resistance range —10 ohms to 100,000 ohms. James Hudson, Handley, Inc., Santa Monica, California.

Circle No. 137 on Inquiry Card.

Small Rate Gyro

A new rate gyro for high altitude rocket research is only 1⅝" in diameter and 3½" long. Despite its extremely small size, it has a d-c motor and pot pickoff. The new instrument is hermetically sealed in a stel case and can withstand temperatures from —65 to +180F, unlimited altitude, vibrations of .06DA to 10 G's, whichever is limiting, 10 to 2000 cps, shock of 75 G's for 6 to 12 millisec. on any axis and 50G acceleration. The motor runs on 28v d-c, 150 ma maximum running current and output pot values met any usual requirements. Humphrey, Inc., San Diego, Cal.

Circle No. 232 on Inquiry Card



Electromagnetic Clutch

A new wet-type clutch permits an almost unlimited variety of spindle speeds, feed and traverse movements and directional changes. Compact design allows as many as 40 clutches to be incorporated in a single machine with mounting on motor shaft or countershaft as desired. The clutch operates on a simple magnetic principle in which annular flux is through the plates. This feature provides high torque capacity and assures automatic wear take-up to eliminate adjustment problems. The steel driven plates have a "sine wave" conformation which overcomes residual magnetism and hydrostatic film strength; plates snap open the instant the coil is de-energized. Twin Disc Clutch Company, Racine, Wis.

Circle No. 170 on Inquiry Card.

Ten Turn Pot

A new series of ⅞" diameter, ten-turn precision potentiometers features rugged stops of 128 oz/in strength to prevent damage to the component or system caused by servomotor overshoot. Two temperature ranges are available: 2 watts at 25C, derating to zero at 85C; 2 watts at 65C, derating to zero at 125C. Both have a minimum operating temperature of –55C. Standard resistance ranges are 10 to 125,000 ohms ± 5% and 300 to 90,000 ohms ± 5%. Standard linearity tolerance is ± 0.50% with best practical linearity of ± 0.05%. Other design features include 0.2 gm.cm.^{2} moment of inertia, 0.6 oz/in starting torque, 0.5 oz/in running torque, 0.6° backlash and 0.003" end play. Helipot, Div. of Beckman Instruments, Inc., Fullerton, Cal.

Circle No. 129 on Inquiry Card

Acceleration Integrating Switch

A normally closed monitoring switch signals the start of the intergration process which at a given velocity, expressed as a product of G and time (G-seconds), closes a normally open switch. Operating ranges are 10 to 25 G-seconds over a detection input of 5-20 G's, with a maximum of 5 consecutive G inputs within a given range. A holding device is incorporated to overcome the earths gravitational field and prevents integration below prescribed levels. The normally open switch has an operating current capacity of 0.20 amp for continuous duty and will stand overload currents up to 5 amps for short periods of time. A ferromagnetic sensitive mass is included to provide a means for testing the integrating switch. Units are filled with inert gas, hermetically sealed, and equipped with solder terminals. Giannini Controls Corp., Pasadena, Cal.

Circle No. 144 on Inquiry Card

Miniature Trimming Pots

Miniature trimming potentionmeters offer resistances ranging from 10 ohms to 125K ±5% with power ratings up to 2¾ watts. They are packaged in ¼ inch diameter cylindrical cases 1.137 inches long with a 0.190 threaded end affording easy panel mounting of up to 16 units in one square inch. The three basic models of the series, the 0250, 0251 and the 0252, are completely sealed surpassing the requirements of MIL-STD-202 Mthd 104B Immersion. CON-ELCO, Monrovia, California.

Circle No. 213 on Inquiry Card

Shaft Position Encoder

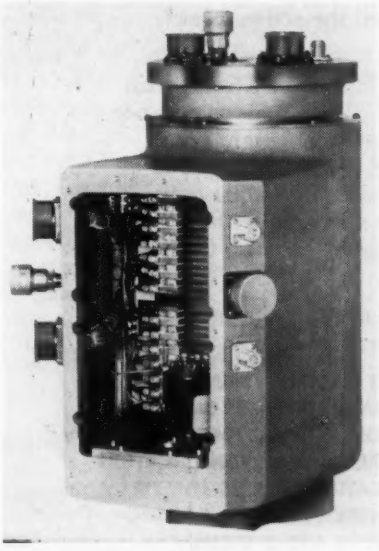
An analog to digital converter, called the "Mem-O-Tizer", is said to contain four features never previously available in one unit: memory; ultra low torque, high accuracy; direct operation of external equipment through one ampere contacts; dynamic readout, "on-the-fly", readout up to 250 rpm. Among the additional features are: no brushes; no contact of electrical circuit during rotation; no ambiguity; bi-directional operation; "chromector" plug-in separable connector, completely sealed unit; guaranteed life over 20 million operations. Telechrome Mfg. Corp., Amityville, N. Y.

Circle No. 171 on Inquiry Card

Miniature Button Switch

Designed to match a line of indicator lights, a miniature push button switch features gold plated contacts with wiping action to assure positive trouble-free operation and low contact resistance. Rated at 100 ma with a life of 500,000 operations, the switch is offered with form A, B or AB contacts. The unit mounts with a single nut in a ⅜" hole. Transistor Electronics Corporation, Minneapolis, Minnesota.

Circle No. 136 on Inquiry Card.



Slip Ring Assemblies

Slip ring assemblies, 38 in number, are components in radar rotating antenna circuits. Each unit includes two coaxial, seven shielded circuits, and 47 unshielded circuits. Dimensions are 24" x 12" x 12". The 56 rings are of coin silver, two silver graphite brushes per ring. Speed equals 15 rpm. Noise level below .002 volts. Superior Carbon Prods., Inc., Cleveland, Ohio.

Circle No. 167 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT

TIME INDEX DIGITALIZER

This visual analog-to-digital converter (VADAC) displays time values in hours, minutes and seconds and simultaneously transmits this information as a coded electrical signal by means of coded drum assemblies and pick-off brushes. Driving pulse advancing drums and interrogating pulses for digital readout are provided from external, user-supplied source.

TYPICAL CHARACTERISTICS

- Range: 00 00 00 to 23 59 59 hrs.
- Input Pulse Frequency: 1/sec.
- Input Pulse Form: Square
- No. of Visual Output Counter Wheels: 5
- Numeral Color: White on Black
- Code: Binary decimal
- Step Time: 30 msec.max. 15 msec.min.
- Operating Position: Any plane
- Brush Load: 50 ma. 40 VDC
- Operating Temperature Range: –54°C +77°C
- Humidity Resistance: per MIL-E-5272A, Proc. 1
- Vibration Resistance: per MIL-E-5272A, Proc. 1
- Shock Resistance: per MIL-E-5400, para. 3.2.20.2.1
- Weight: 1.75 lbs.
- Operating Life: 1000 hrs.

Write for complete data.

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CIRCLE 47 ON INQUIRY CARD

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ELECTROMECHANICAL COMPONENTS

Parametric Amplifier

A low noise regenerative parametric amplifier assembly for the 100-200 mc frequency range exhibits receiver noise figure below 2 db (maximum) over the specified tuning range when used together with a good low noise receiver of 6-8 db noise figure. The unit's circuit is designed to provide flexibility of operation and general experimental versatility. The amplifier consists of a single stage, coaxial resonant cavity 16½ inches high by 4 inches in diameter with tuning controls provided for resonating signal and idler with injected RF pump power. A suitable Varactor diode and spare are supplied with each amplifier. The instrument is available complete with suitable pump oscillator, power supply and interconnecting cables and fittings. The particular features are: extremely low noise figure; large dynamic range; immediate recovery from temporary overload and resistance to damage from incident power levels; phase coherence of output signal; reduction of cross modulation interference; varactor diodes require no d-c bias and do not depend upon a high temperature cathode. Microwave Assoc., Inc., Burlington, Mass.

Circle No. 142 on Inquiry Card

Drift-Free Electromicrometer

Digital readout electromicrometer which makes possible 0.003%/°F transducer specifications at 1000F is designed to measure microinch displacements to an accuracy of ±0.1%. Operation is as follows: a variable permeance transducer consisting of two matched impedances forming half of an inductive bridge is located at the point of desired measurement. The inductive balance is varied by means of the translation of an alloy 15 radiation resistant slug attached to the test specimen. The external bridge balance consists of an identical variable permeance transducer which is driven to a null position by means of a closed loop servo system which uses an exclusive double demodulator to eliminate quadrature. The mechanical system which drives the balance slug is coupled to a digital indicator. The displacement transducer excitation voltage is self-contained in the instrument and is common to both the measuring and balancing transducers, making the output independent of carrier voltage changes. Technical Industries Corp., Pasadena, California.

Circle No. 134 on Inquiry Card

New Electronic Components For Electromechanical Systems

25-Amp Silicon Rectifiers

Fourteen silicon, stud-mount, medium current rectifiers—seven conventional types with the stud as the cathode and seven reverse current types with the stud as the anode—have peak inverse voltage ratings from 50-volts through 600-volts. All types are rated at a forward current of 25 amps and have a maximum one cycle surge current rating of 300 amps. The maximum leakage current at full load is 5 milliamps for the 50-volt units down to 2 milliamps for the 600-volt units, in a single phase circuit at a stud temperature of 145C. The common sources of thermal fatigue have been eliminated by the use of high temperature hard solders and welds for all external and internal joints and seals. General Electric Company, Syracuse, New York.

Circle No. 188 on Inquiry Card.

Hi Temp Resistors

A new line of precision wirewound resistors operate at 205C and maintain 0.1% accuracy from −65C to ±185C. The new resistors utilize a "thermal cushion" design, which minimizes resistance change with temperature. They also use new winding techniques, bobbin designs and high temperature potting compounds. Models available range from miniature printed circuit types of 0.10 watt power rating and 35 K maximum resitance, to axial lead types of 2 watts and 3.5 megohms, and lug types of 2¼ watts and 7 megohms. Nominal minimum resistances and tolerances are: 50 ohms, 1%; 100 ohms, 0.5%; 200 ohms, 0.25%; 500 ohms, 0.1%; and 1000 ohms, 0.05%. All units are hermetically sealed and the encapsulant is fungus- proof, non-hydroscopic, and resistant to 205C. The resistors meet or exceed mil specs. Hamby Corporation, Canoga Park, Cal.

Circle No. 215 on Inquiry Card.

Frequency Converter

Newly designed frequency converter has an input of 120V, 60 cycles, and an output of 115V, 400 cycles, 250 watts square wave. It operates at any temperature between −30C and +52C and is not damaged by temperature extremes to −65C and +85C. It meets all shock and vibration specifications for military ground equipment. Power Sources, Inc., Burlington, Mass.

Circle No. 128 on Inquiry Card.

Signaling Controller

The signaling controller for two position control action can be used with any transducer generating a dc signal, such as thermocouples, tachometer generators and load cells. Corrective action of the controller occurs almost simultaneously with detection of any input signal deviation. It is sensitive enough to react to a change of but one microvolt. Calibration accuracy is within ±0.25% of full scale span or 5 microvolts. Ranges are available from 1 to 100 microvolts. Thermo Electric Co., Saddle Brook, N. J.

Circle No. 227 on Inquiry Card

Compact 235-Watt Transformer

Small size, high temperature, 235-watt transformer mounts in an area only 1 29/64″ thick x 2 29/64″ wide, and is 3″ high. This compact size results from the use of widely distributed, shallow windings of high temperature wire providing a short thermal path. Fully encapsulated and hermetically sealed in a steel container, this transformer is designed to meet MIL-E-5272B, and MIL-T-27A, Class "S". Primary voltage on standard units is 115V, 400 cps, with secondaries available from 5 to 2000 volts. Terminals are arranged in rows of 5 pins—one for the primary, three for secondaries, and an additional one for use as a center tap on secondary windings. Life expectancy: 10,000 hours. Regulation: 5% max., no load to full load. Ambient temperature: −55C to ±100C. Arnold Magnetic Corp., Los Angeles, Cal.

Circle No. 220 on Inquiry Card.

Signal Generator

A new digital controlled signal generator designed specifically for use with FM telemetry discriminator systems, provides continuous automatic correction of output frequencies. Frequency range is 100 cycles to 100kc, with .02% accuracy at all frequencies. Maximum settling time is one second to stabilize to a new preset frequency. The unit is crystal referenced. Compact in size, the chassis is 8¾″ in height, intended for standard rack or instrument case mounting, and includes power supplies. Digital Instrument Laboratories, a subsidiary of Telemeter Magnetics, Inc., Los Angeles, Cal.

Circle No. 126 on Inquiry Card.

BASIC BUILDING BLOCKS FROM KEARFOTT

Size 8

INTEGRATING MOTOR GENERATOR

This high performance unit is the smallest of its type available today. Accurate in the Kearfott tradition, this motor generator is thermistor compensated and characterized by an output of .5V/1000 RPM, linearity of .06% from 0-3600 RPM and output variation of temperature (—15°C to +75°C) of ±.4% from the value at 25°C.

TYPICAL CHARACTERISTICS

MOTOR SECTION	Phase 1	Phase 2
Voltage (volts)	26	40
Frequency (cps)	400	400
*Current (amp)	.119	.077
*Power Input (watts)	2.3	2.3

GENERATOR SECTION	
Excitation: 26 V., 400 cps, .067 amps., 1.4 watts.	
Volts @ 1000 RPM	.5
Phase Shift @ 3600 RPM	0°
In Phase Axis Error (mv)	1.5
Quadrature Axis Error (mv)	3
Linearity @ 3600 MPH (%)	.06

*Values measured at stall

MECHANICAL CHARACTERISTICS	
Weight (Oz.)	3.9
No Load Speed (RPM)	5500
Stall Torque (Oz.)	0.22

Write for complete data.

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Lexington Road, Winston-Salem, North Carolina

Electronic Components

Sinusoidal Oscillator

Silicon transistor oscillator is an epoxy encapsulated unit designed to create a sine wave signal source. Stability as a function of supply voltage and temperature have been emphasized together with rugged reliability. The small size, stability, low distortion and ruggedness of the unit makes possible the concentration of a large number of discrete control and information functions per unit volume and weight. Power supply problems are simplified by the use of a single supply with very low current drain for each oscillator (28 volts at 1 ma). Solid State Electronics, Sepulveda, Cal.

Circle No. 152 on Inquiry Card

Thermocouples

Complete line of mineral insulated thermocouples, called Conax Con-O-Clad, provide flexibility that permits bending into unlimited configurations; high temperature range up to 3,000F; small size probes from .040″ to .375″ OD sheath; fast response rate which is practically instantaneous; long life with thermocouple wires encased by inert minerals in air tight chamber; shock and vibration proof; and corrosion resistance from a wide choice of sheath metals. Many standard methods of termination and mountings are available for ready installation into systems. Conax Corp., Buffalo, New York.

Circle No. 164 on Inquiry Card

Sub-Miniature Pulse Transformer

Using a clamped ferrite, core-gapped construction instead of the conventional toroid and cup core, a new subminiature pulse transformer provides improved voltage breakdown and insulation resistance. This unique design also features faster reset and less B_r, higher power capabilities, lower losses, and increased total flux swing capability. The transformer, formally known as the Micro-Stat is constructed on an armite form for precise winding geometry to control leakage inductance and distributed capacity. The Micro-Stat has a polished gap which represents ½ mil of effective gap and the unit is available in either epoxy construction or in hermetically-sealed metal casings. Pulse Engineering, Inc., Santa Clara, Cal.

Circle No. 130 on Inquiry Card.

Precision Flush Circuits

Flush circuits consist of electrical conductors in unlimited configurations which have been imbedded in surrounding dielectric materials to exacting flush tolerances. The durability, high conductivity, extreme fineness of detail, minute size, and micron flushness of the inlaid circuit makes it ideal for any application in which smooth, electrical noise-free brush or wiper action is required. Angular tolerances of 5 seconds of arc over 360° and dimensional tolerances of .0002″ can be achieved. The circuits can be flushed to less than one micron with a finish of better than five micro inches. The units are available in a great variety of materials, a typical construction consisting of a silver circuit imbedded in a layer of epoxy with an aluminum base. Scientific Components, Inc., Santa Barbara, Cal.

Circle No. 172 on Inquiry Card

Modular Power Supply

A midget-sized power supply which does a mammoth job is believed to be the largest fully-transistorized power supply. It can furnish 17 different closely-regulated and unregulated levels of power for all types of data processing and computing machines. Weighing 1,490 pounds and measuring 5′ high by 5′ wide by 1¾′ deep, the system's total output is 5.8 kilowatts. A unique feature is a built-in transistor test circuit which makes it possible to tell in a matter of minutes, without shutting down the power supply, if any of the system's 200 power transistors are defective. By packaging each of the 17 power supplies as an individual plug-in component, the system makes it possible for an operator to replace an entire power supply in a matter of seconds. Bogue Electric Manufacturing Co., Paterson, N. J.

Circle No. 217 on Inquiry Card.

Miniature Hi-Voltage Filter

A hi-voltage filter, with a unique method of keeping caps from shaking loose due to vibration is designed for 4000 volts. The filter has a special silver plating for anti-corrosion and conductivity with self-locking anti-corona caps. All parts are formed or machined at a tolerance of .001, with screw-on connectors. Filtron Company, Inc., Culver City, Cal.

Circle No. 159 on Inquiry Card

Hi-Temp Power Supplies

Precision regulated power supplies operate at such temperature extremes as +120C and −55C. The units are silicon transistor regulated with silicon rectifiers, tantalum capacitors, and a zener diode reference. Characteristics include low ripple and low output impedance. Arnoux Corp., L. A., Cal.

Circle No. 221 on Inquiry Card

Instrument Amplifier

Small, light-weight, high reliability AC amplifier designed primarily for missileborne and airborne instrumentation utilizes silicon transistors throughout and meets MIL-E-8189 and MIL-T-5272. It is a low-level AC charge amplifier with high impedance input. Input signal range is from 0 to 660 millivolts with a variable gain up to 20. Output impedance is approximately 5000 ohms. Wurlitzer Company, North Tonawanda, New York.

Circle No. 239 on Inquiry Card.

Military-Type Transistor

Military-type 2N1120—a high current, high-power switching transistor—now in production meets spec MIL-T-19500/68 (SigC). Its maximum collector current rating of 10 Adc makes it particularly appropriate for high current switching applications, while a collector-emitter voltage rating of 70 Vdc suits it to high voltage application. It will readily dissipate 45 watts at a 25°C mounting base temperature. Bendix Semiconductor Prods., Long Branch, N. J.

Circle No. 256 on Inquiry Card.

Precision Sub-Miniature Fuse

New sub-miniature fuse, known as Micro-fuse, measures only .205″ dia. x .270″ long. Development is based on bead type construction which with a new type of filament wire permits uniform and very close resistance tolerances and high reliability in blowing characteristics across the wide range from 1/500 amp thru 5 amps at 125 volts. Blowing specifications are: Life —100% of rating; 0-10 seconds—150% of rating. Littlefuse, Inc., Des Plaines, Ill.

Circle No. 248 on Inquiry Card.

BASIC BUILDING BLOCKS FROM KEARFOTT

PRECISE ANGLE INDICATOR

Consisting of an angle position indicator, motor and servo amplifier, this small, versatile, rack panel mounted unit provides angular position indications for laboratory, production and field use. Input signals proportional to unknown angular position of synchro device being measured are resolved as an error voltage, which is amplified and used to drive an internal servo loop to null. Counter mechanism then provides direct visual readout of angular position.

TYPICAL CHARACTERISTICS

Input Signal: S_1, S_2, and S_3 of external synchro transmitter.

Repeatability: Within 0.6 minute in either a clockwise or counterclockwise direction for any angular position.

Readability: 0.5 minute through full range from zero to 360° Rotation is continuous.

Accuracy: ± 6 minutes in the standard unit. Other accuracies available on request.

Sensitivity: 0.5 minutes maximum.

Slewing Speed: Phase sensitive, 180° in 7 seconds.

Input Voltages: 115 volts, single phase, 400 cycles, 23 VA max.

Size: Standard Rack Mounting—1¾″ x 9½″ x 8½″

Write for complete data.

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CIRCLE 51 ON INQUIRY CARD

POST DECITRON ELECTRONIC PRODUCTS

NEW!
MH-2-P Magnetic Switch

A new and improved sensing device . . . neatly contained in an epoxy resin shell. The MH-2-P is ideal for industrial applications and is easier to mount in areas of limited access. A quick disconnect Cannon connector eliminates elbow type construction.

The new epoxy resin housing results in less magnetic flux and increased sensitivity. As a consequence, smaller magnets can be used and manufacturer reports a minimum magnetic field transient time of only 8 milliseconds is needed to activate the switch. Operating life is in excess of one billion operations.

Write For Bulletin MH-2-P

Decitron

ELECTRONIC PRODUCTS DIVISION

Post Machinery Co. | 175 Eliot St., Beverly, Mass.

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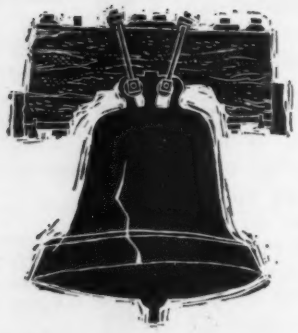


VIBRATION

Analysis problems on precision mechanisms used in stable platforms have created staff openings with the outstanding Inertial Guidance group in the country. Address your letter to Mr. C. T. Petrie, Manager, Research & Engineering Staff.

LITTON INDUSTRIES Electronic Equipments Division
Beverly Hills, California

Electronic Components

Metal Film Resistor

A new molded, precision, metal film resistor features low controlled temperature coefficient, low noise level and high stability under severe humidity conditions. According to the manufacturer, this new metal film resistor offers performance that equals or surpasses a precision wire wound resistor, yet is smaller, lower in cost, also gives better RF performance, plus uniformity in size over wide resistance ranges. It is available in five sizes, ⅛ through 2 watts. The Electra Mfg. Co., Kansas City, Mo.

Circle No. 257 on Inquiry Card

600 CPS Servo Amplifier

Transistorized, 60 cps servo amplifier is designed to drive a size 18 servo motor from synchro, resolver, or AC pot data. Twin controls are provided for gain and damping with which the loop performance can be optimized. The 762A has a built-in power supply, and operates directly from the 117V 60 cps line. Full output is obtained for 200 mv.RMS, into the input impedance of 100K. The amplifier's carrier phase shift is +90°. Damping is adjustable, error-rate. Weight 3¼ lbs; and dimensions, a miniaturized 6⅛″ x 2⅞″ x 4¼″. Typical applications are positional servos with pot, synchro and resolver data. Typical loops are servo-driven indicators, multipliers, digitizers and repeaters. Connections to the unit are simple: 2—input, 2—line power, 3—motor. Industrial Control Co., Lindenhurst, L. I., N. Y.

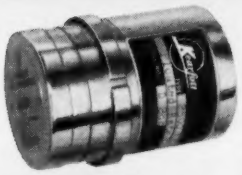
Circle No. 258 on Inquiry Card

Silicon Power Rectifier

New silicon power rectifier (Type 439) provides up to 240 amps of forward current per cell with maximum peak inverse voltage ratings up to 600v. Maximum reverse leakage current is 50 milliamps at the rated peak inverse voltage. Characteristics include: operation a high ambient temperatures—up to 190°C at the junction; solid copper base for ruggedness; and small size—with maximum cell length of 3″ and overall weight of 8 ozs. A hermitically-sealed cell, the unit is nickel-plated to maintain low contact resistance and prevent corrosion. The rectifier case is the cathode (positive) terminal. Ceramic insulation between the anode and cathode provide a greater creepage distance than previously available on high-voltage, high-current silicon rectifiers. A ¾″ stud on the case permits mounting of the cell in any position. Westinghouse Corp., Pbg, Pa.

Circle No. 259 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT



FLOATED RATE INTEGRATING GYROS

Specifically designed for missile applications, these Kearfott miniature gyros operate efficiently at unlimited altitudes. Their outstanding accuracy and performance make them superior to any comparably-sized units on the market. Hermetically sealed within a thermal jacket, these gyros are ruggedly designed and completely adaptable to production methods. Performance characteristics that are even more precise can be provided within the same dimensions.

TYPICAL CHARACTERISTICS

Mass Unbalance:
Along Input Axis: 1.0°/ hr maximum untrimmed
Standard Deviation (short term):
Azimuth Position: 0.05°/hr
Vertical Position: 0.03°/hr
Drift Rate Due to Anisoelasticity
Steady Acceleration:
.015°/hr./g² maximum
Vibratory Acceleration:
.008°/hr./g² maximum
Damping:
Ratio of input angle to output angle is 0.2
Characteristic Time:
.0035 seconds or less
Weight: 0.7 lbs.
Warm-Up Time:
10 minutes from −60°F
Life: 1000 hours minimum

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

20 SECOND SYNCHRO

This synchro, just one of a broad line offered by Kearfott, provides the extreme accuracy required in today's data transmission systems. Kearfott synchro resolvers enable system designers to achieve unusual accuracy without the need for 2-speed servos and elaborate electronics. By proper impedance, matches up to 64 resolver control transformers can also operate from one resolver transmitter.

TYPICAL CHARACTERISTICS — SIZE 25

	Transmitter	Control Transformer
Type Resolver		
Part Number	Z5161-001	Z5151-003
Excit. Volts (Max.)	115	90
Frequency (cps)	400	400
Primary Imped.	400/80°	8500/80°
Secondary Imped.	260/80°	14000/80°
Transform. Ratio	.7826	1.278
Max. Error fr. E.Z.	20 seconds	20 seconds
Primary	Rotor	Stator

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

MINIATURE VERTICAL GYRO

Provides accurate vertical reference in the form of two 400 cps synchro signals proportional to sine of gimbals' displacement about pitch and roll axes. Gravity-sensitive vertical reference device provides electrical signals directly to torque motors which maintain gyro spin axis perpendicular to earth's surface. Hermetically sealed and impervious to sand, dust, sun, rain, salt, spray, humidity or fungus as specified in MIL-E-5272A.

TYPICAL CHARACTERISTICS

Free Drift Rate:
Within 0.5° in one minute time.

Shock:
The gyro operates satisfactorily without damage after 60g shock of .015 seconds duration.

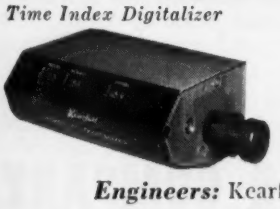
Hermetically Sealed:
These instruments are hermetically sealed and are not affected by sand, dust, sunshine, rain, humidity or fungus conditions.

Operating Temperature Range:
Gyros operate in ambient temperatures below —20°C to +100°C. A maximum of 3 minutes of operation at 400°F will not damage these gyros nor impair their accuracy.

Weight:
5.5 lbs. approximately.

Write for complete data.

Time Index Digitalizer



Precise Angle Indicator

Size 8 Integrating Motor Generator

Engineers: Kearfott offers challenging opportunities in advanced component and system development.

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ON GYROS
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ON MIN. GYROS
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Now 4 CHR High Temperature TEFLON® Tapes

Temp-R-Tape adheres securely to bar heated to 520°F during high temperature resistance test.

Pressure-Sensitive TEFLON Tapes

easy to apply in both electrical and mechanical applications

The electrical uses of Temp-R-Tape include slot lining, interlayer and interphase insulation, harness bundling, wrapping for microwave components, transformer coils, capacitors and high voltage cables, etc.

As a low friction, non-stick facing, Temp-R-Tape applications range from facings for film guides in sensitive electronic instruments to the facing for heat sealing bars, forming dies, chutes, guide rails, etc.

Chemical resistant facing applications include masking tape in high temperature dipping operations.

All four of these pressure-sensitive Teflon tapes are available from stock in rolls and in sheet form. In addition to Teflon tapes, CHR also makes a fiberglass tape with thermal curing, pressure-sensitive silicone adhesive (Temp-R-Tape GV) and silicone rubber coated fiberglass tape with thermal curing, pressure-sensitive silicone adhesive (Temp-R-Tape SGV).

FREE SAMPLES and folder — write, phone or use inquiry service.

— −100°F to 500°F applications

— Class H and Class C insulation

— Non-stick and low friction facing

— Chemical resistant facing

TEMP-R-TAPE T is a .006″ pressure-sensitive Teflon tape with −100°F to 400°F (−70°C to 200°C) temperature range. It has high dielectric strength, low power factor, negligible moisture absorption, high elongation, is non-corrosive and non-contaminating. Meets Class H Temperature requirements.

TEMP-R-TAPE TH is a .013″ pressure-sensitive Teflon tape with −100°F to 400°F temperature range. It is similar to Temp-R-Tape T except that it is made of .010″ Teflon film to which .003″ silicone polymer adhesive has been added. Often used where a single, thicker dielectric barrier is desired or where a more rigid, abrasion resistant wrap is required.

TEMP-R-TAPE C is a .002″ pressure-sensitive, thermal curing Teflon tape with −100°F to 500°F temperature range. It is made with a cast Teflon film which provides dielectric strength (2750 v/m) higher than any other type of Teflon film. When cured in place, it will operate at temperatures up to 500°F and will withstand much higher temperatures for short periods. Meets Class H and Class C temperature requirements.

TEMP-R-TAPE TGV is a thermal curing, pressure-sensitive Teflon impregnated fiberglass tape with −100°F to 500°F temperature range. Although it is used extensively for mechanical and electrical applications, its dielectric strength is lower than other Temp-R-Tapes.

CHR products include:

COHRlastic Aircraft Products — *Airframe and engine seals, firewall seals, coated fabrics and ducts*

COHRlastic Silicone Rubber Products — *Silicone rubber moldings and extrusions, silicone rubber sheets, silicone sponge rubber*

Temp-R-Tapes — *Pressure sensitive, thermal curing Teflon and silicone tapes*

Allied Products — *COHRlastic silicone cements and conductive gasketing*

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Leader In Fabrication of Silicone Rubber

CONNECTICUT HARD RUBBER COMPANY

Main Office: New Haven 9, Connecticut

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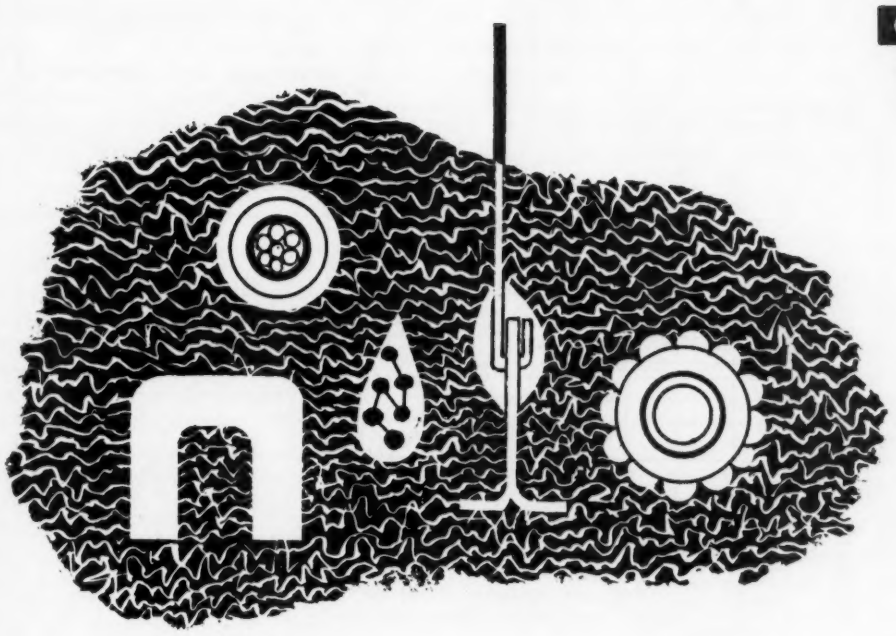
COMPONENTS DIGEST 10



Materials and Techniques for

High Temperature Components

New aircraft and missile component specifications appear to be continually extending upper temperature limits. This trend severely taxes manufacturers of components and materials who are beset by difficult specifications, usually with relatively small production followup. This Components Digest reviews the design and materials problems involved in producing components for operation to several hundred degrees centigrade and develops from this information some of the important selection factors in specifying components for high temperature applications.

For this limited maximum temperature radically new materials or design concepts are not required. However, careful design and use of the best of existing materials is essential. After a brief introduction, we will survey the following items: insulation, conductors and solder joints, magnet wire, magnetic materials, fits, bearings and lubricants, mechanical and environmental problems. The Digest includes summaries of design principles.

While brief reference is made to a number of specific components, the reader is referred to previous Components Digest issues for additional details. These earlier Digests include temperature and material considerations.

THE HIGH TEMPERATURE PROBLEM

High temperatures sharply accelerate chemical reaction rates, and introduce significant changes in physical characteristics. These two aspects of the high temperature problem lead directly to the difficulties normally encountered in high temperature component design. Lubricants evaporate or oxidize. Dimensions of mechanical parts vary, affecting important fits, such as with bearings. Insulation resistance decreases, leading to dielectric breakdown. This occurs with greatly increased rapidity at higher temperatures. Parts which have not undergone adequate stress relief may distort permanently. Materials (such as encapsulative resins and plastics) may soften and experience a permanent distortion (important in precision devices such as synchros and potentiometers). Oxidation of varnishes and insulations is sharply accelerated, for example see Fig. 1, from AIEE Standard No. 57, Oct. '55, Proposed Test Procedure for Evaluation of the Thermal Stability of Enamel Wire, showing typical insulation life versus temperature for enamelled magnet wire. Unequal coefficients of expansion or non-uniform expansion lead to over-stressing and permanent distortion. Cracks may develop in plastics, permitting the entrance of moisture leading to ultimate dielectric breakdown. Unequal thermal expansions in mating parts can change critical fits, break hermetic seals, etc. Evaporation products of uncured varnishes can fill air gaps, deposit on contacts, or deteriorate the atmosphere in hermetically sealed components. Solder joints may oxidize and open. These phenomena are not all-inclusive, but are typical of the variety of problems encountered in meeting high temperature specifications.

Insulations

High temperature electromechanical devices require insulation systems capable of functioning at the required ambient temperature plus the internal temperature rise for the life of the unit. For satisfactory performance, a compatible group of insulations is required to serve the various insulating functions. Typically, a compatible system includes: a magnet wire insulation, in-

COMPONENTS DIGEST

sulation between magnet wire and magnetic iron, either a rigid form, or a flexible lining, insulation between separate coils, terminal insulators, insulating caps or covers, tying cord, insulating varnish, insulated leadwire, and sleeving to cover electrical connections. Sometimes insulating members serve structural functions, such as when a coil form is used as a mounting surface for terminal lugs. An appropriate soldering or brazing technique is required in conjunction with the above insulations to join magnet-wire to magnet-wire, or magnet-wire to lead-wire in a reliable high temperature connection. This subject is considered at length in a later section of this Digest.

INSULATION SELECTION FACTORS

In selecting an insulation, the primary requirement is its ability to maintain adequate dielectric strength under the required voltage and temperature conditions for the life of the unit. Often just as important are the simple, mechanical properties that affect ease of handling. Obviously overly brittle materials are unsuitable for lining the slots of an electric motor. Space factors, indicating the percentage of total available coil area actually occupied by useful copper, also limit the use of otherwise satisfactory materials such as glass. Space factors become increasingly important in miniaturized high voltage components. Table I tabulates the factors to consider in choosing an insulation. Note that compatibility is a major item. It is possible for example that the impregnation varnish may incorporate a solvent deleterious to some other element of the insulation system. A high temperature varnish in a low temperature system may require a curing temperature which is damaging to the insulated magnet wire for instance.

TABLE I

Insulation Selection Factors

1. Easy to handle, can be shaped to required configuration without flaking, cracking, developing small breaks, etc.
2. Adequate dielectric strength.
3. Good space factor.
4. Compatible with other elements of insulation system.
5. Withstand environment, particularly high temperature and humidity.
6. Withstand temperature shock (followed by humidity) without developing cracks and absorbing moisture.
7. Low moisture absorption.
8. Minimum internal strains or change in shape under environmental stress.
9. Low in cost.
10. Does not flake or give off harmful residues which may clog airgap or injure precision bearings.

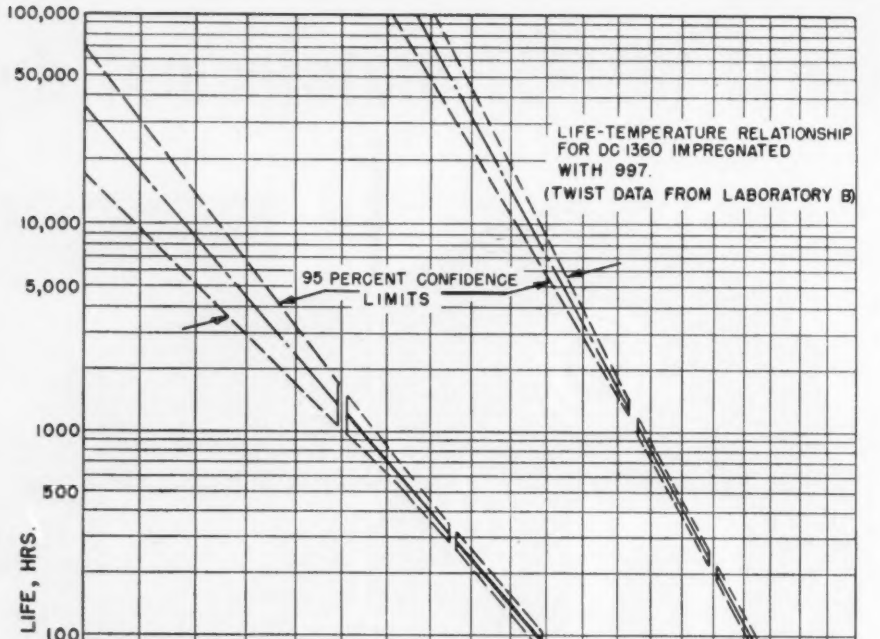


Fig. 1—Example of life-temperature characteristics.

EVALUATING INSULATION SYSTEMS

Insulation systems are tricky. Notwithstanding all the advice of the insulation manufacturer, it is still necessary to perform complete tests on samples of the final product. Items such as the varnish curing time, as well as many handling techniques, are best determined through use. Similarly, evaluation of the insulation system in regard to other than high temperature environments is necessary.

Humidity has always been a particularly severe environmental problem, particularly in conjunction with temperature cycling. Temperature shock may deform or crack some insulating plastics. Table II summarizes the typical environments to which insulation may be subjected. Note that a relatively new environment, resistance to nuclear radiation, may be quite damaging to common high temperature insulation.

A convenient laboratory procedure for evaluating insulation systems is based upon the use of motorettes.

TABLE II

Typical Environments to Which Insulation Systems May Be Exposed

High humidity
Temperature variation
Temperature shock
Salt Spray
Megger and high voltage dielectric tests
Fungus
Nuclear radiation

These have been described in AIEE Standard No. 510, and consist essentially of "models" of wire and insulation designed to simulate conditions in electromechanical structures, such as motors. They are especially useful for conducting large scale comparison tests economically. However, suitable performance of an actual item must always be verified by actual test.

INSULATING MATERIALS

As explained above the choice of insulation materials is a complex function not only of life and temperature characteristics, but also of mechanical properties related to ease of handling in use, as well as the abilty to withstand severe environments. Mechanical requirements are especially important: (a) In small components where relatively little room is available for insulation, and (b) Where insulation serves structural as well as dielectric purposes. The list of suitable materials diminishes sharply for the higher temperature range, see Table III taken from a paper (*The Effect of Properties of Materials for 1000°F Motors on Design Voltage for Optimum Specific Output*) presented at the SAE National Aeronautic Meeting in Los Angeles, Oct. 1959, by E. A. Linke, Chief Motor Engineer, Airborne Accessories Corp. For temperatures above 600F, compromises are necessary in selection of materials. Special materials must be developed and often "composite" materials are required which combine the better properties of several materials, no one of which is entirely suitable. Table IV, also taken from Mr. Linke's SAE paper, shows the effect of 1000F exposure on materials normally suitable to 600F.

For convenience and as a basis for standardization, classes of insulation have been defined by the AIEE. Table V lists these classes and briefly describes their application. Unfortunately the best of the high temperature Class H materials are pushed to their limits to achieve even modest life at temperatures to 600F. Materials for use above 600F have not as yet been classified. As mentioned previously, insulation materials are often combined to achieve a required overall suitability for these very high temperatures.

Reporting on "*A 600F Airborne Electrical System*" at the October SAE National Aeronautic Meeting, John J. Pierro, Project Engineer at North American Aviation Inc. included a general discussion of insulation materials for high temperature equipment. The following paragraphs are taken from Mr. Pierro's discussion.

He said that, in equipment designed to operate in a 600F ambient, insulations include both inorganic and organic materials, but the majority of applications require the higher temperature capability of inorganic materials. In the temperature region above 600 to 700F the more conventional resins and polymers such as silicones and teflons become unsuitable; inorganic materials are required.

Silicone and teflon insulations, he said, are capable of withstanding higher temperatures for longer periods of time than common knowledge indicates. For example, polytetrofluoroethylene has been repeatedly and successfully tested for periods of time up to 500 hours at temperatures of 650F without significant degradation of the material. The condition of the material after test indicated that considerably longer life could be expected. Softening of the material does occur at these temperatures and mechanical stress must be avoided, particularly cut-through-type stress. Similarly, he said, certain silicone resins are capable of at least 500 hour life at 600F. Higher temperature capability results if the resins are highly filled with inorganic materials.

TABLE III

Available Insulating Materials For Different Temperature Ranges

* —65 to 300 °F ‡* —65 to 600 °F
†‡* —65 to 1000 °F

* Paper	‡* Viton
* PVC (mod)	‡* Silicone Elastomers
* Formvar	‡* Silicone Glass
* Polyesters	‡* Silicone-Mica
* Melamines	†‡* Asbestos
* Phenolics	†‡* Samica
* Alkyds	†‡* Aluminum Silicate Paper
* Epoxies	
* Mylar	†‡* Isomica
* Nylon	†‡* Recombined Mucovite Mica Paper
* Isonel	
* Alkanex	†‡* Integrated Phlogopite, Silicone Bonded
* Kel-F	
* Teflon	†‡* Micalex
* Neoprene	†‡* Oxide Coatings
* Butyl Rubber	†‡* Porcelain
* Hycar	†‡* Electrophoretically deposited mica

TABLE IV

Effect of 1000F Exposure On Materials Used for 600F Motors

INSULATION

Silicone varnish becomes sandy deposit. Fiber glass—Mica becomes brittle and weak, but remains intact.

CONDUCTORS

Copper, nickel clad. Nickel infuses copper, changes conductivity. Resistance goes up 3 to 1 with temperature change.

MAGNETIC

Electrical sheet. Core loss decreases, surface oxidizes. Permeability decreases 10 to 15%.

Table V

AIEE Standard Definitions of Insulation Classes

CLASS O 90C

Materials or combinations of materials such as cotton, silk and paper without impregnation. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 90C.

CLASS A 105C

Materials or combinations of materials such as cotton, silk and paper when suitably impregnated or coated or when immersed in a dielectric liquid, such as oil. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 105C.

CLASS B 130C

Materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable binding substance. Other materials or combinations of materials not necessarily inorganic may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 130C.

CLASS F 155C

Materials or combinations of materials such as mica, glass fiber, asbestos, etc. with suitable binding substances. Other materials or combinations of materials, not necessarily inorganic, may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 155C.

CLASS H 180C

Materials or combinations of materials such as silicone elastomer, mica, glass fiber, asbestos, etc. with suitable binding substances, such as appropriate silicone resins. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 180C.

CLASS (....) 220C

Materials or combinations of materials which by experience or accepted tests can be shown to be capable of operation at 220C.

CLASS C OVER 220C

Insulation that consists entirely of inorganic materials such as mica, porcelain, glass, quartz and similar materials. Other materials or combinations of materials may be included in this class if by experience or accepted tests that can be shown to be capable of operation at temperatures over 220C.

COMPONENTS DIGEST

Inorganic materials may be required to meet hot spot temperatures up to 1000F found in power equipment designs. In inorganic insulations, Mr. Pierro said, the field is narrowed to a relatively few choices by a combination of mechanical and electrical requirements. The materials most generally used and found useful in the temperature range from 700 to 1000F are mica, glass, quartz, alumina, refractories such as magnesium oxide or zirconium oxide, mixtures of the above in the form of cements and to a limited extent asbestos. One widely used insulating medium is fabricated from a layer of mica supported by a layer of glass cloth on one or both sides of the mica. The glass cloth provides mechanical strength, while the mica provides the electrical properties. These are usually impregnated with a material that allows flexibility at low temperature for ease of fabrication but which burns out at high temperature or converts into a non-conducting medium after exposure to high temperatures. Glass, on the surface, would seem to possess some very desirable high temperature insulation properties. However, unfortunately many types of glass become relatively good conductors at high temperature. Certain glasses, utilizing heavier elements, although somewhat "lossy" are usable, at least up to 1000F. Lead borate glass is an example of this. Aluminum phosphate has found wide application as a binder for cements and sheet insulations and appears destined to become one of the fundamental elements of many high temperature insulation systems.

Two important deficiencies of inorganic insulations have become evident, Mr. Pierro said. One is lack of resiliency, the other is porosity that makes moisture proofing difficult. Lack of resiliency in inorganics so often found in present day insulations is the major villain and very special attention must be devoted to prevent cracking of insulation under mechanical or thermal stresses. Particular attention, he said, must be paid to matching thermal coefficients of insulator and insulated elements and to special mechanical designs that take into account the limited tensile strength of the insulations. These problems are not so severe for fixed applications such as motors, generators and transformers where lack of flexibility and porosity can be designed around. But, he said, flexible moisture proof insulated wire capable of withstanding 1000F without a metal jacket has proven to be the most difficult insulation problem for which a solution has not yet been found.

Insufficient attention has been paid by design engineers to the possibilities of applying inorganic insulators as structural components in electromechanical assemblies. For example, bonded mica —combining high mechanical strength, high dielectric strength, high durability and moisture resistance, low weight, resistance to oils and organic solvents, low thermal conductivity and high stability are currently used in the manufacture of brushes, discs, slot liners, field coil insulators, small stampings, commutator end rings, channels and troughs. However, for most of these applications the bonded mica is essentially applied for its excellent electrical insulation characteristics. Little if any attention has been applied by design engineers in considering this material for applications requiring two or more of its property groups for application as structural members in electromechanical assemblies.

Components in these assemblies calling for moderately good structural strength properties combined with thermal insulation and electrical resistance can be made from mica, in many cases effecting savings in cost as well as reducing the number of parts.

Here are some typical examples of bonded mica that according to New England Mica Company of Waltham, Mass. could be considered for other high temperature applications than the ones currently used:

● Rigid insulation made from selected india mica splittings bonded with silicone resin and thermoset under heat and pressure. The material exhibits high mechanical strength and integration, and incorporates the high thermal stability, excellent electrical insulating characteristics and durability of both mica and silicone resins. It was designed especially for use in Class H motors, special motors designed for overload conditions, small space factor, or unusual ambient temperatures. Use of amber mica, in place of india mica, with silicone resins increases the high temperature performance of the insulation.

● A permanently flexible insulation comprising selected mica splittings bonded with silicone resin, characterized by high heat resistance, high electrical insulating characteristics, excellent chemical, weather and moisture resistance and designed for use as Class H insulation.

● Mylar and mica, comprising layers of selected mica films, carefully overlapped and bound between facing layers of mylar, incorporates the superior electrical insulating properties and unusual mechanical characteristics of mylar.

● Electrical asbestos and layers of selected mica splittings, carefully overlapped and bound with facing layers of electrical asbestos, incorporates the high thermal stability of electrical asbestos.

● Flexible sheets made of fiberglass cloth (untreated or varnish treated) and mica splittings bonded with a flexible plastic organic resinous binder. The combination incorporates in a single insulating material the high tensile strength and temperature resistance of fiberglass cloth, plus the electrical insulating characteristics of bonded mica, plus a high degree of flexibility and mechanical integration. Fiberglas-mica insulation can be wrapped around rods of small diameters without cracking, slippage or delamination, and retains its flexibility over a long period of time. It exhibits high dielectric strength at both ordinary and operating temperatures and is recommended for use as slot liners, phase insulation, core insulation and coil wrappers in all standard applications of Class B insulation.

● Flexible sheets of silicone-treated fiberglas and carefully selected mica splittings bonded with silicone resin to form a combination sheet insulating material which incorporates the high thermal stability, high electrical insulating qualities, and excellent resistance to the action of chemicals, weather and moisture of mica, glass-cloth and silicone resins. They are designed for use

Various configurations of bonded mica made by New England Mica Co.

McDONNELL VOODOO

Above 1200 mph, it isn't enough to put just mechanical "muscle" at the pilot's command; he needs an assist with "mental" aerobatics, too.

Teaming-up with McDonnell engineers, the specialists of the Aeronautical Division at Minneapolis-Honeywell Regulator Company turned out a mechanical co-pilot specifically for the F-101B. For nerves and sinews in this M-H Autopilot, they specified Hitemp Teflon* coated wire and cable.

As the leading specialist in high temperature insulated wires and cables, Hitemp Wires, Inc. is proud to stand among those devoted to safeguarding our country.

HITEMP WIRES, INC.

1200 SHAMES DRIVE, WESTBURY, NEW YORK

*Registered trademark for Du Pont fluorocarbon resins.

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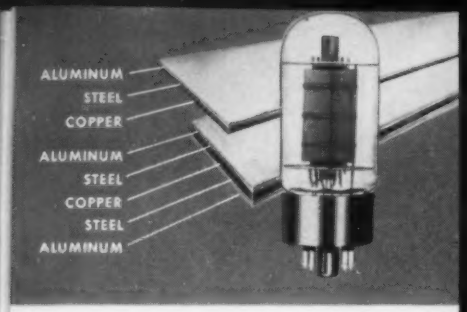
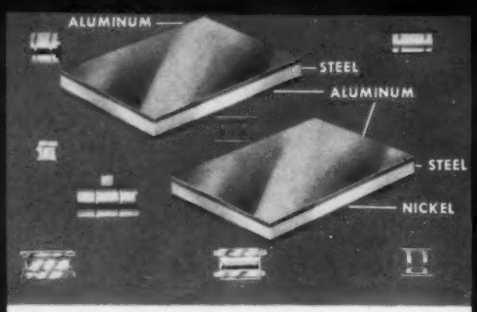


ALIRON® Copper-Base and Copper-Cored

Three-layer and five-layer materials used for anodes in rectifier and amplifier tubes. Provide longer power output life . . . uniform heat dissipation . . . high electrical conductivity . . . improved anode reradiation . . . and reduce costs.



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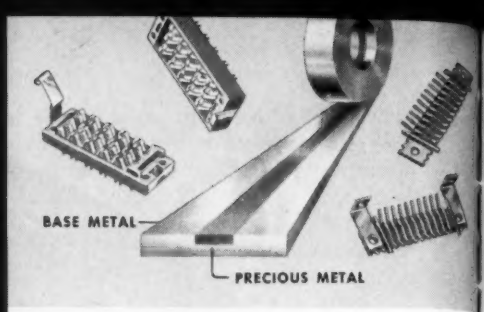
These clad metals are used as alternate materials for solid pure nickel in electron tubes. They conserve critical material . . . reduce costs substantially. Supplied in annealed coils ready for your production.



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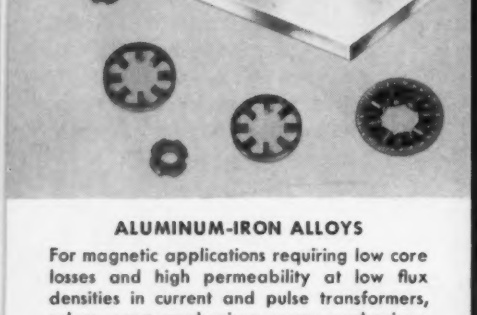

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Single and double inlay, overlay and toplay provide better electrical performance, longer operating life and lower fabrication costs. Complete assemblies can be made to close tolerances by single blanking and forming operations.

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Platinum Metals • Reactor Metals • Radio Tube & Transistor Metals

CIRCLE 50 ON INQUIRY CARD

COMPONENTS DIGEST

as Class H insulation and in special motors designed for overload conditions, small space factor, or unusual ambient temperatures.

Many other such formulations exist: Part II of this digest to be published in March, 1960, will list the significant properties of bonded mica formulations as well as other types of insulation material.

Space Factors of Electrical Insulation

In his SAE paper cited above (SAE National Aeronautic Meeting, Oct., 1959) Mr. E. A. Linke of Airborne Accessories Corp. points out strikingly the importance of space factor in the slots of small electrical motors for high temperature application. Although the points he makes are aimed specifically at a 2″ diameter, 4-pole, 3-phase 400-cps motor, they apply more generally to all high temperature electromagnetic components.

He makes the point that the reduced conductivity of copper at high temperatures coupled with the bulkier insulations required, substantially reduce the overall conductivity of a coil having a fixed overall volume, and reduce its effective output (ampere-turns) per watt of input. He makes a strong case for low voltage ratings where fewer turns and reduced insulation thickness can markedly increase the ratio of copper to total available area. Figs. 2 through 7, taken from Mr. Linke's SAE paper, show numerically the relationships among copper space factor, voltage rating and output.

Conductors

Mr. John J. Pierro's SAE paper cited in the previous section on high temperature insulation materials also discussed conductors for high temperature.

Only two practical conductors have evolved for very high temperature applications: silver and copper. While silver is in many respects an ideal conductor for high temperature, Mr. Pierro pointed out its high cost and high density make it undesirable where large quantities are required. Although copper has a severe oxidation problem in the temperature range of 600 to 1000F it has been generally adopted. Much time and effort, he said, has been devoted to establishing the best method of protecting the copper against oxidation with minimum increase in resistivity.

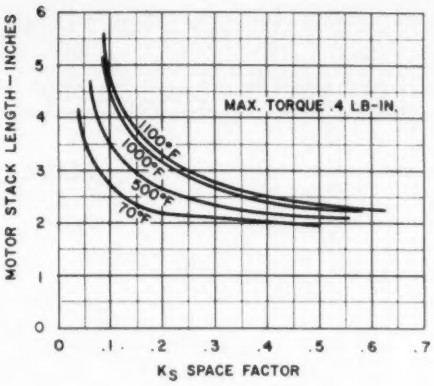

Fig. 2—Motor stack length vs space factor (2 inch diameter, 4 pole, 3 phase, 400 cycle motor). These curves illustrate the increased stack length required to compensate for loss of conductivity due to poor space factor. The increased importance of this relationship at high temperatures is clearly indicated.

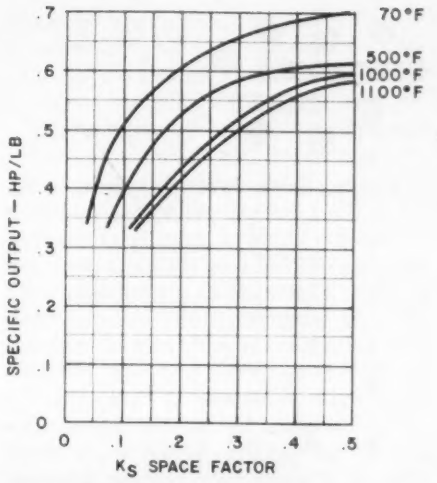

Fig. 3—Effect of space factor on output (2 inch diameter, 4 pole, 3 phase, 400 cycle induction motor). Note the substantial loss in output for the poor space factors, particularly at elevated temperatures.

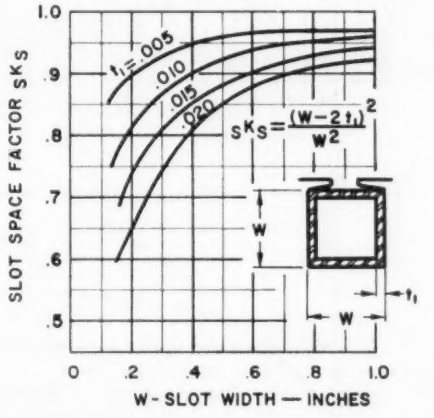

Fig. 4—Effect of insulation thickness and slot size on space factor. The slot insulation is a major item contributing to poor space factor in small high-voltage motors, particularly at high temperatures where insulations have poorer handling and fabricating qualities. The problem is aggravated where insulation is required between motor windings.

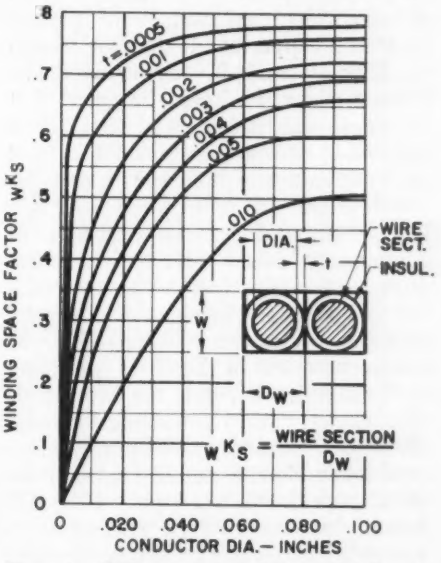

Fig. 5—Effect of insulation thickness and wire diameter on space factor. In figuring space factor for the wire, a uniform rectangular array of conductors is assumed. Wire insulation plus space between wires contribute to reduced space factor.

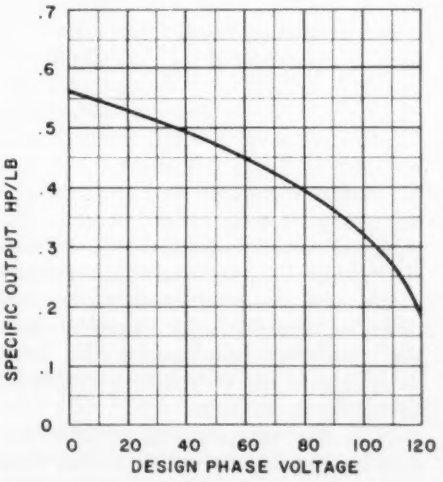

Fig. 7—This figure ties together the preceding figures by relating output to voltage rating.

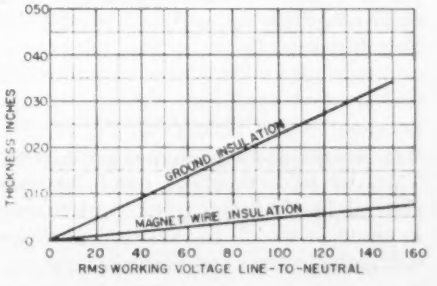

Fig. 6—1000°F insulation requirement. Typical required insulation thickness as a function of rated voltage. The deleterious effect of insulation thickness on space factor and the importance of space factor in high temperature motors, suggest the use of low voltage ratings typically in the neighborhood of 26 volts.

COMPONENTS DIGEST

The methods investigated have all taken the form of preventing oxidation of the copper by a coating of another material. Nickel and stainless steel are perhaps most used as a protective coat although inconel has also been utilized. The objective in applying a coating, he said, is to obtain a minimum thickness since thickness is reflected directly in terms of resistivity and ultimately as weight. While early work utilized a protective coating approximately equal to 30% by weight of the total conductor, more recent work has been aimed at coatings of 5 to 10 percent by weight. The lighter coating allows an increase from approximately 70 percent conductivity (IACS) to 90 percent. The performance of several protected copper conductors are shown on Figs. 8 and 9, taken from Mr. Pierro's paper. It should be noted that the curve shown for 10 percent nickel coating is only applicable to the most perfect platings of the non-porous type.

While the use of a protective coating greatly reduces the oxidation of copper, Mr. Pierro said, it does introduce another problem which is a mixing or diffusion between the copper and the protective coating. The diffusion produces a band of an alloy at the junction between the two metals that grows with time. Unfortunately, the alloys formed are relatively poor conductors and a net increase in resistivity with time results. This diffusion, he said, is most noticeable in very small cross section conductors and may be tolerable in large cross sections. Where the diffusion can not be tolerated a boundary material relatively inert to both copper and the protective coating has been utilized very effectively to minimize this effect.

Pierro pointed out that all practical conductors known to date have a positive increase in resistance with temperature. From Fig. 8 it can be seen that a very significant increase of approximately 3:1 occurs for copper over the temperature range considered. This, he said, must be carefully considered in all designs and particularly in those in which the resistance of the conductor governs performance.

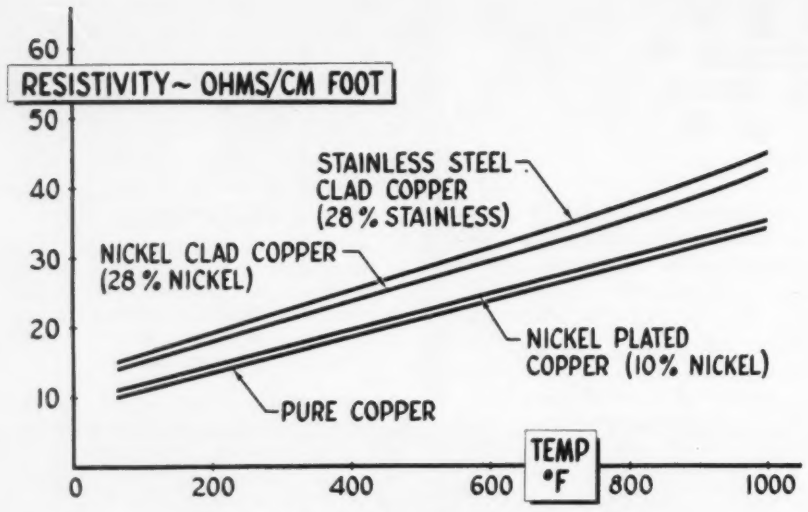

Fig. 8—Resistivity vs temperature for copper conductors with various types of protective coatings.

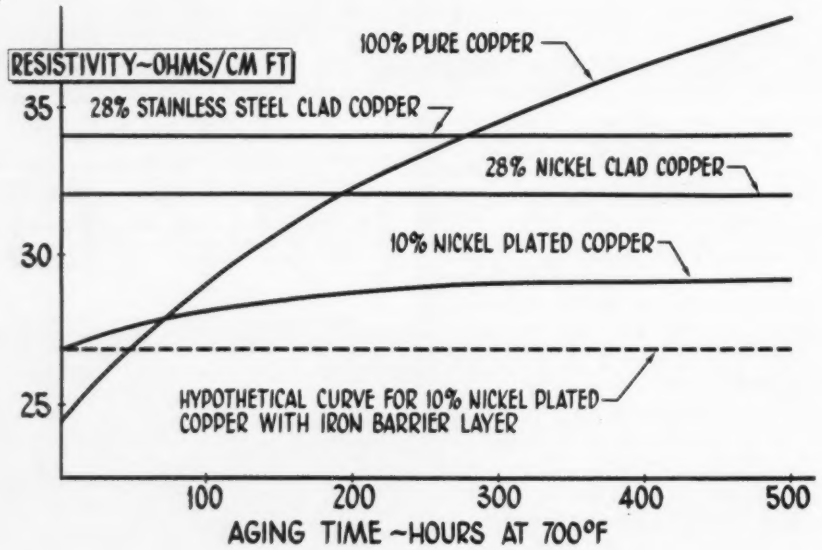

Fig. 9—Resistivity vs aging time at 700F for copper conductors with various types of protective coatings.

Soldered Connections

Information in the section is taken from a paper by G. L. Branch and R. Y. Scapple of Hughes Aircraft Co., presented by Mr. Branch at the Third Electronic Industries Association Conference on Reliable Electrical Connection in Dallas, Texas, December, 1958.

A particularly important aspect of high temperature design of electromechanical devices has to do with soldered connections. These must not only function reliably at high temperatures but also withstand humidity exposure for extended periods, and the standard salt spray exposure. Since most of the soldered connections used in a weapon system involve electronic and electromechanical components, it is imperative that the soldering operation and the resulting flux residue be nondamaging to the components under all operating conditions.

With the exception of tin-lead solders having low tin content (less than 19%) all tin-lead solders begin to melt at the eutectic temperature of 361F. For most applications, 300F or thereabouts would be considered the maximum operating temperature. Since demands exist for soldered connections to function at 400F to 500F it is apparent that a high temperature solder and flux capable of withstanding severe environmental requirements must be used. The Hughes investigators found that such a solder is available and may be purchased to conform to a standard Government Specification (QQ-S-571, Ag 1.5).

In addition to selecting a suitable solder alloy and flux, it was necessary to determine a suitable soldering technique to be used with the high temperature solder. In general, the conventional soldering iron used for electronic component assembly is not capable of generating sufficient heat to melt the high temperature solders. A larger iron, although capable of generating sufficient heat, would be

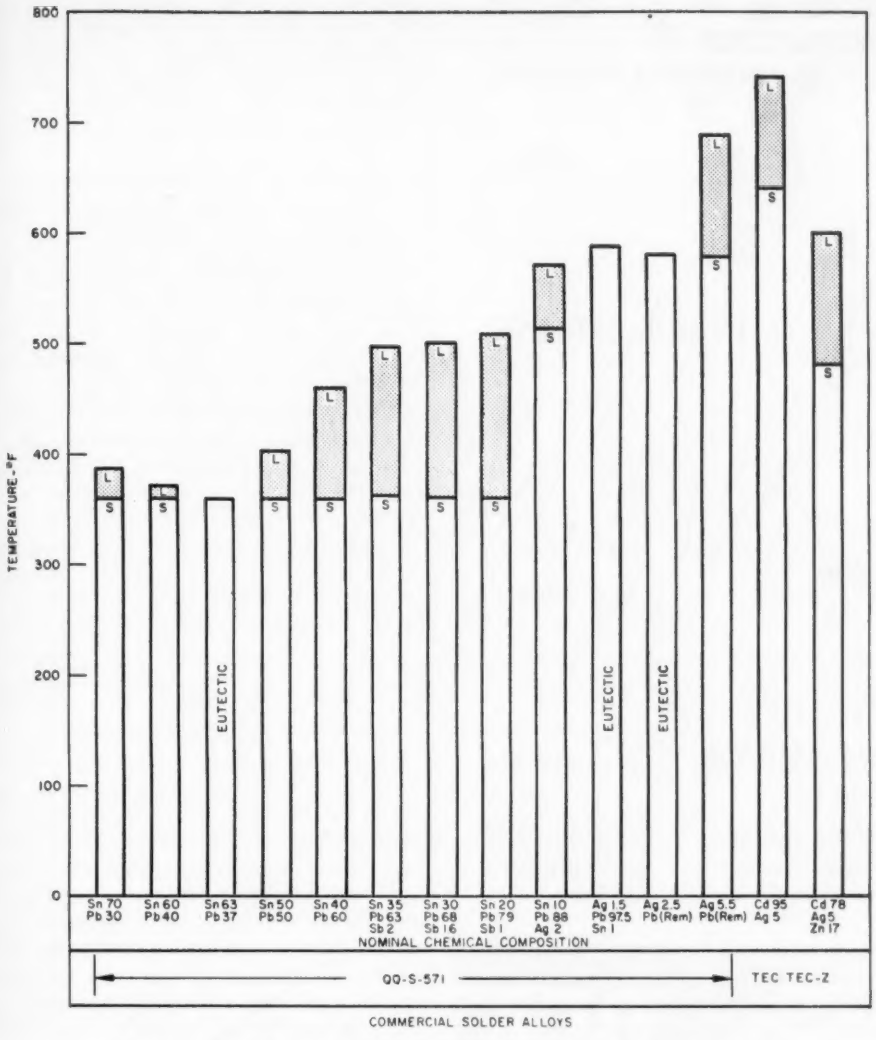

Fig. 10—Solidus and liquidus temperatures of soft solder alloys.

impractical in the electronics industry where miniaturization is continually decreasing the accessibility of components. The soldering technique Hughes engineers found to be ideal was resistance soldering.

Resistance soldering has numerous advantages, they said. The heating electrodes require little space and are therefore suitable for miniaturized components and areas having limited accessibility, the heating is localized and rapid, thus minimizing the amount of heat that will be conducted into the component, and finally, sufficiently high temperature can be easily and reproducibly achieved.

In addition to choosing a suitable solder alloy and soldering technique, it was necessary to determine the type of plated surface or surfaces that offer the required combination of good solderability and resistance to degradation by the imposed environments. Hughes engineers determined that copper conductor wires clad with either silver or nickel (silver for the lower temperatures and nickel for the higher temperatures) met these requirements. In addition, they found that a gold plate deposited over a nickel plate or a rhodium plate deposited over a silver plate were suitable plating schedules for elevated temperature applications. Of primary importance in considering these various platings and base materials was the effect of heat aging for extended periods of time at elevated temperature. The extent of metallic diffusion between the base metal and the platings and between the platings themselves was one criterion for determining the suitability of platings for elevated temperature application.

SOLDER ALLOY

The Hughes engineers conducted a survey of the commercial solder alloys currently produced by solder manufacturers to determine a suitable alloy or alloys possessing the necessary requirements. The solder alloy had to be capable of maintaining sufficient mechanical strength in the operational temperature range, have a solidus temperature sufficiently higher than the maximum operating temperature to insure reliability and a liquidus temperature low enough to simplify soldering techniques. Another primary requirement was that the solder alloy be corrosion resistant and not degraded by the operational environments.

The solidus and liquidus temperatures of various commercial solder alloys currently produced are depicted graphically in Fig. 10. The majority of these commercial solder alloys were eliminated for use in the 400-500F temperature range because of too low a solidus temperature. The silver-lead binary solders were not applicable for use because of their susceptibility to corrosion in humid environments. This is a definite uncertainty as to the applicability of the cadmium base silver solders due to insufficient substantiating data in regard to corrosion resistance, the inability of procuring this alloy in small strand sizes and in the form of a flux core solder. The only solder alloy deemed worthy of investigation was the lead base eutectic alloy, AG 1.5 per QQ-S-571, having an approximate composition of 1.5% silver, 1% tin and remainder (97.5%) lead. The ability of this alloy to resist corrosion in humid environments is attributed to its tin content. The availability of this alloy with a flux core and in appropriately small strand sizes was confirmed by several solder manufacturers.

Mechanical property tests were conducted on the bulk solder alloy Ag 1.5 to determine the effect of elevated temperature environments for short and extended durations on the mechanical strength of this alloy. Even though mechanical strength is not considered a primary requisite of a soldered connection it is indicative of the inherent capabilities that a soldered connection will possess at elevated temperatures. In addition, certain applications occasionally require the soldered connection to function as a mechanical joint as well as an electrical joint.

Tension test specimens were cast from the bulk solder. The effect of temperature (both short and long time exposures) on the tensile strength and elongation are depicted in Fig. 11.

ENVIRONMENTAL EXPOSURE

To determine corrosion resistance and galvanic compatibility of the conductor wire, flux and solder alloy, Hughes engineers submitted representative specimens containing the activated flux residue and specimens with the residue removed to the following environmental tests: (1) Salt Spray Test per MIL-E-5422 (50 hours duration) (2) Humidity Test per MIL-E-5422 (10 days duration) (3) Thermal Shock Test per MIL-STD-202, Method 107 (consisting of 25 cycles, range —80 to 500F). (4) Heat Aging Test per MIL-

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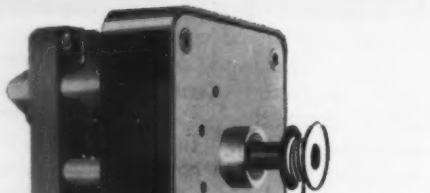

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CIRCLE 58 ON INQUIRY CARD

COMPONENTS DIGEST

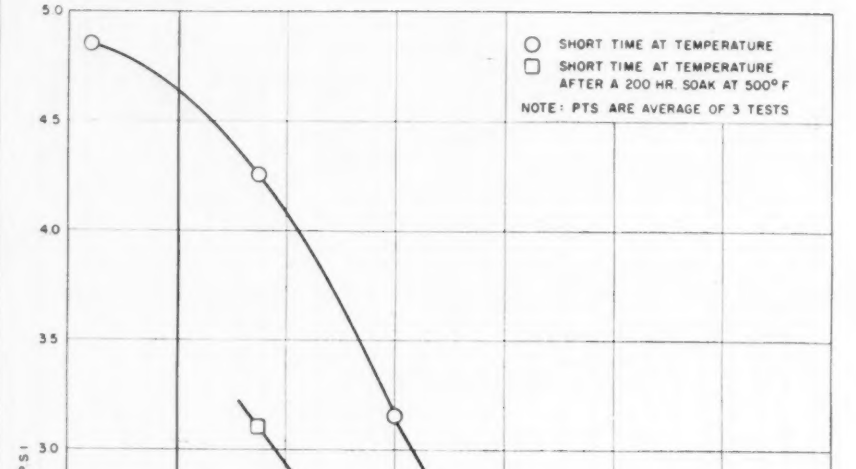

Fig. 11—Effect of temperature on tensile properties of Ag 1.5 Bulk Solder Alloy.

E-5272 (200 hours duration at 500F).

Upon completion of these tests, microscopic examination, conducted at 10X magnification, revealed no evidence of corrosion products on the solder joints, wires or pins. The silver plated conductor wire showed evidence of surface discoloration as a result of oxidation incurred by the heat aging test. The thermal shock test caused no degradation to the wires, pins or solder joints.

The Hughes investigators concluded that:

1. The resistance method of soldering is capable of consistently producing a uniform solder connection with a high degree of reproducibility.

2. For 500F operation the following platings will provide good solderability and resistance to metallic diffusion:

a) Gold plate over nickel plate.

b) Rhodium plate over silver plate.

c) Nickel plate over copper base metal. Gold plate over silver plate and silver plate over copper base metal are not satisfactory for 500F operation.

3. Solder alloy Ag 1.5 per QQ-S-571 has satisfactory strength and corrosion resistance to withstand 500F operation plus additional severe environmental requirements.

4. Flux residue (volatilized or non-volatilized) must be removed from high impedance circuits if a high degree of reliability is required.

5. Soldered connections when exposed to environmental testing (500F

for 200 hours, salt spray for 50 hours, humidity test for 10 days, and thermal cycling from −80F to 500F) show no evidence of corrosion. Mechanical properties will be decreased by an amount depending on the testing temperature and the materials used.

Ball Bearings for High Temperatures

Probably the most unreliable feature of high temperature electromechanical equipment is in the bearing-lubrication system. Even in instrument type mechanisms where loading is relatively light, long life is difficult to achieve at temperatures above about 150°-200°C.

In instrument applications the big problem is the maintenance of a suitable film of lubricant in the bearings. At elevated temperatures, lubricants evaporate rapidly, often leaving a gummy residue. Oxidation hastens chemical reactions which destroy the lubricating properties of greases. Due to space limitations it is generally impossible to feed lubricant at a prescribed rate by means of wicks or other popular lubricating mechanisms. Grease reservoirs, while used frequently, are inadequate for life requirements of a thousand hours or more at 200°C. The lubricant supply is all too soon exhausted. Schemes such as extra wide bearings, special bearing designs, double bearings with a grease supply in the intervening space, or more complex feed systems have been tried. Unfortunately, long life has yet to be achieved. Present miniature rotating components may operate for several hundred hours at approximately 180°C ambient temperatures using conventional Class H insulation and standard lubrication techniques. Higher temperature operation for thousands of hours must await major new developments in lubricants and/or lubrication system design.

Many lubricants are covered by military specifications, (see Tables V and VI). Selecting these requires a knowledge of many factors other than maximum temperature. Factors such as speed of rotation, friction torque at low temperatures, permissible friction loss in the bearings, as well as design factors such as the quantity of lubricant to use, must all be considered. Table VII summarizes these application factors.

While proper lubrication is the major factor affecting bearing life, there are other design factors meriting attention. High on the list is the matter of bearing fit. This is particularly important where wide temperature range combines with differentials in the expansion coefficients of mating surfaces, resulting in major changes in fits. A differential expansion of several thou-

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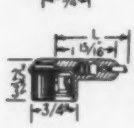
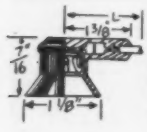
Clip this out — keep handy for part numbers and specs on connectors below for either ¼" or ⅜" top caps. Prefix 90 for ¼"; 91 for ⅜". Lead wire 18" long from center of cap or length to your specs.

#90 or 91SCCSL beryllium copper contact, cadmium plated nests in anti-corona cup. Silicone rubber insulation throughout.

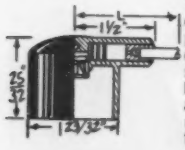


#90 or 91SCCRSL beryllium copper contact, cadmium plated nests in anti-corona cup. Silicone rubber insulation throughout. Takes up to one watt resistor — specify value and tolerance.

#90 or 91SCCDSL beryllium copper contact, cadmium plated nests in anti-corona cup. Skirt clings to tube — guards against flash-over Silicone rubber insulation throughout.



#90 or 91SCCDRSL beryllium copper contact, cadmium plated enclosed in anti-corona cup. Skirt clings to tube — helps suppress corona—guards against arc-over. Takes up to one watt resistor. Specify value and tolerance.



#90 or 91CCSTLRL beryllium copper contact, cadmium plated nests in anti-corona cup. Glass-filled silicone insulation on cap; silicone rubber on lead. Long skirt for arc-over. Takes up to 2 watt resistor. Specify value and tolerance.

Besides new silicone types — Alden provides a complete series of connectors for ¼", ⅜" and 5/16" cap in your choice of phenolic, mica, polyethylene, nylon and Kel-F. Complete hi-voltage cable assemblies are available using Alden hi-voltage disconnects and tube cap connectors.

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CIRCLE 73 ON INQUIRY CARD

TABLE VI (a)

Temperature And Speed Limitations Of Greases And Oils

GREASE	MAX SPEED (BORE IN MM X RPM)	TEMPERATURE RANGE (DEGREES F)
DC-44 (MIL-G-15719A)	200,000	−50 to +350 (1/3 rated load only)
*(F,L,M) DC-33	200,000	−100 to +350 (1/3 rated load only)
Supermil M40	200,000	−50 to +350 (1/3 rated load only)
Supermil M100	200,000	−100 to +350 (1/3 rated load only)
Versalube G300	200,000	−100 to +350
*Shell ETR-B	200,000	−50 to +450 (1/3 rated load only)
*Beacon 325 (MIL-G-3278A)	400,000	−25 to +250
Lehigh L793 (MIL-G-15793)	400,000	−25 to +250
Texas TG 1888 (MIL-G-7421A)	400,000	−100 to +200
*Andok C	400,000	+25 to +300 (OR Rotation)
Calol OHT (MIL-L-3545)	500,000	+10 to +300
Shell 5A (MIL-L-3545)	500,000	+10 to +300
Red Horse Industrial	500,000	−60 to +150
*Andok C	600,000	+25 to +300
*Unitemp 500	600,000	−50 to +450 (Best for high speed at high temp. for short life)
*Regal Starfak Special (MIL—L—7711) meets original spec but does not meet latest revision.	600,000	−50 to +200 (Best for high speed)

*Preferred over operating conditions indicated. (See SA-345)

Notes:
1. To approach high limit of temperature, speed and load must be low.
2. To approach maximum speed, temperature and loads must be low.
3. If speed and temperature are both high, loads must be low and life will be short.
4. Speed limits except as otherwise indicated pertain to inner ring rotation. For outer race rotation values are 60% of those shown.

OILS	MAX SPEED (BORE IN MM X RPM)	TEMPERATURE RANGE (DEGREES F)
GE F50	200,000	−75 to +600 (Spray)
DC 710	500,000	0 to +625 (Spray)
MIL-L-6081A, or 1010	1,400,000	−40 to +350 (Spray)
MIL-L-6085A & MIL-L-7808C	1,400,000	−60 to +350 (Air Mist) −60 to +450 (Spray)
MIL-L-9236A Target Spec (WRGL-34,L825)	1,400,000	−40 to +450 (Air Mist) −40 to +550 (Spray)

Courtesy Barden Corp.

See Also Table VI (Temperature Range Selection Chart For Oil, Grease, And Dry Film Lubricants) which appeared in our September issue on page 58.

sandths of an inch is typical of steel against aluminum in motors of about 2 inches in diameter. For this reason, where possible, coefficients of expansion should be matched over the entire temperature range. Where steel bearings are used in aluminum housings, steel inserts are suggested as bearing seats, although a common material (steel) for the entire frame is preferable. Fig. 12 shows thermal dimensional changes, and Table VIII explains the effects on bearing fits. Obviously these fits are important at any temperature at which the bearing is operating. Equally important is minimization of loading by proper alignment minimization of magnetic loads, balancing and avoidance of axial loading due to unequal expansions of shaft and housing assembly.

Shaft fits should be somewhat tight. Barden engineers generally recommend 0.00005 tight to 0.00035 tight for most applications. Clamping of inner races is essential, they say, since a temperature differential between inner race and shaft could otherwise cause looseness and poor heat transmission from the inner race (a heat source) to the shaft.

Housing fits should be loose. Barden generally recommends 0.0001 to

COMPONENTS DIGEST

0.0005 loose for most applications. They warn that the outer race of at least one of the two bearings must be free to slide to avoid overload or zero thrust as the shaft expands with heat.

Materials factors are also important, (see Table IX and X). The bearing material must be free of aging effects or dimensional change resulting from long periods of exposure to extreme temperature. Surface corrosion, which may generate small abrasive particles must be held to an absolute minimum. Mechanical properties, particularly hardness, must be suitable to sustain the load during the required life of the bearing. Temperature stabilized bearings, designed for dimensional stability at high temperatures are often

Fig. 12—Relative growth or shrinkage for bearing dimensions versus the difference in coefficients of thermal expansion between bearing materials and either the housing or shaft materials over a 1000F temperature range.

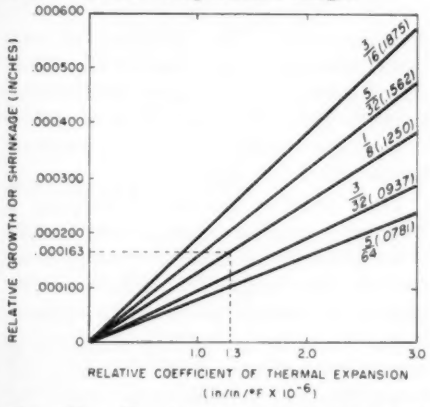


Fig. 12a—For bearing dimensions 1/4 inch and up.

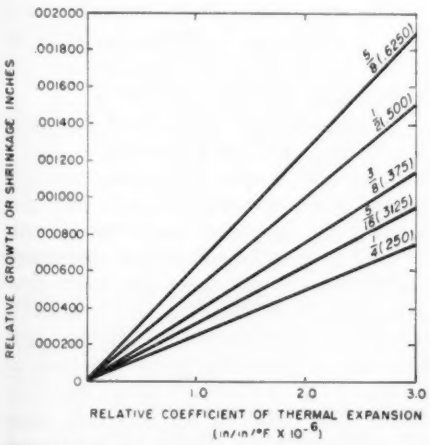
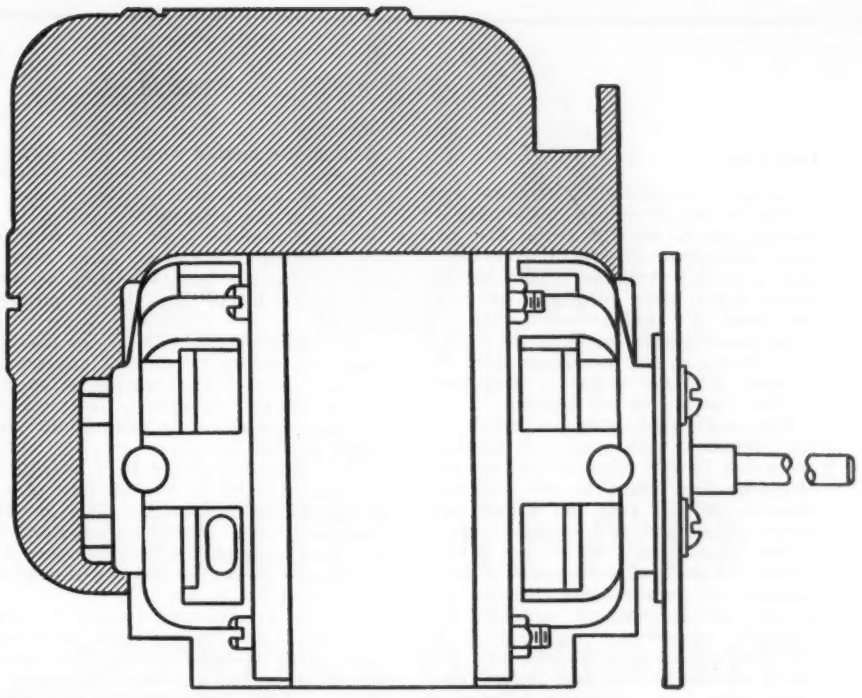


Fig. 12b—For bearing dimensions less than 1/4 inch.



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*Name on request.

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CIRCLE 62 ON INQUIRY CARD

TABLE VII Lubrication Application Factors

GREASE

A grease is a semi-solid lubricant consisting of an oil and a thickening or gelling agent, usually soap. The primary advantage of grease over oil is that it makes available to the bearing many times more lubricant, reducing the need for re-lubrication. On the other hand, grease increases the torque by a factor of ten to twenty over oil, at least until the grease is channelled by the running of the bearing.

The soaps used today are usually of the lithium or soda type; calcium base soaps are largely obsolete in the precision bearing field. The oils used with these soaps fall into the broad categories of mineral and synthetic oils.

The large variety of greases results from the need to fulfill such a large number of requirements that no one grease can be entirely suitable. For example, greases are required to be fluid enough to allow starting at —65F yet to operate at 400F and higher. They must offer low resistance to motion, yet be consistent enough to stay in the bearing.

A rotating ball bearing is similar to a churn. It works the grease, attempts to sling it out of the bearing, centrifuging it toward the outer ring. The grease in turn restrains rotation, impeding the motion of the balls and retainers increasingly with larger quantities of grease and higher speeds.

One of the properties required in a grease, therefore, is its ability to withstand working. It must resist separation of the oil from the soap, as well as undue thickening of the mixture or gel.

The composition of a grease also affects its ability to stand high speeds. Certain greases can operate at speeds about one-half as high as oils; others, notably the silicones, only about one-sixth as high as oils.

The life of a grease in a bearing is greatly affected by the amount of air available to it, and for this reason, labyrinth seals should be provided to minimize pumping of air; pressure differentials across the bearing should be prevented by design.

Ability to withstand storage for long periods is also an important characteristic. Oil oxidation and volatilization tends to harden a grease and render it useless. Little information is available on the storage reliability of the various greases. However, greases with good high temperature stability generally have the largest storage life. MIL-G-3278 greases generally can be stored for two years under normal conditions.

Factors affecting the selection on the right grease for each application are given below:

SPEED

Speed is usually expressed in Dn, multiplying the bore size in millimeters by the top rpm expected. For example, a 100 size bearing which has a 10 mm bore operating at 60,000 rpm has a Dn of 600,000. This is the highest Dn that present day greases can stand and life can be expected to be measured in weeks rather than months or years at these speeds.

Usually oils are to be preferred at Dn speeds above 400,000.

The silicone greases are unable to operate satisfactorily at speeds above 200,000 Dn. These greases are particularly useful in low speed, light load, high temperature applications, for example, small fan motors for electronic gear.

TEMPERATURE

Most greases are limited to 300F or below, some to 250F., 200F or even 150F. One silicone grease will stand 400F, and two greases 450F but for short periods only. In fact, for all greases, life is severely penalized by each extra increment of temperature. Recent military needs call for operation at

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recommended. The problem of material selection is so complex that close coordination between user and bearing manufacturer is required during the component design stage for extreme temperature applications.

One effective means of keeping a bearing operating at high temperature is to furnish excess capacity; the extra margin can make the difference between successful operation or failure.

For example, a bearing designed to carry 1,000 lbs at 400F can lose between 20-40% of its capacity when the temperature increases to 500F and an additional 20% at 600F.

The use of split ballbearings to provide a maximum carrying capacity in a bearing of a given size can be advantageous in such application.

In general, the component designer should use as large a bearing as possible, supply ample lubricant, provide means where possible of uniformly delivering the lubricant, keep the bearing as cool as possible, match temperature coefficients to guarantee fits, keep oxygen away from bearing and lubricant, minimize temperature gradients, and provide a generally good mechanical design. Of course, where possible heavy heat sinks or an adequate supply of cooling air should be employed to reduce internal temperature rises.

tion at 500F and even 600F. Such possibilities are limited by the lubricants available. Today no greases tested at Barden have met these requirements. For many devices having military end use, cold starts are required, restricting the use of greases whose limiting operating temperatures do not go below 0° F.

LOAD

The silicones should be used only up to 1/3 rated load for the applicable speed and bearing size. Other greases can be used at full rated load.

CONSISTENCY

Consistency is that property of a grease which causes it to hold together. It is measured by the depth of penetration of a ball in a given time interval; the greater the penetration, the lower the consistency.

High consistency greases are required for outer ring rotation, where centrifugal force acts to sling the grease out of the bearing.

Vertical axis applications in which gravity tends to make the grease flow away from its design position also require greases of high consistency.

Table XI compiled by Barden Corp. summarizes the important factors relating to proper bearing application.

High Speed Bearings

The following section covers bearings for speeds exceeding 600,000 DN (Bore in mm x Speed in RPM). At extreme speeds, bearing selection, mountings, alignment, lubrication and fitting practice become very critical to a point where conventional mounting practice no longer assures reliability and long life. This discussion based on information obtained from the Barden Corp. is intended as a guide to the designer to enable him to properly select and apply bearings for this type of service. Generally the higher the speed and/or the temperature, the greater the need for design which favors the bearings.

BEARING SELECTION

Angular contact bearings run at speeds to DN = 1,500,000 and higher in the larger sizes with the proper selection of retainer material and design. The angular contact bearing lends itself to extreme speeds better than any other bearing type because the retainer can be very light in weight and of

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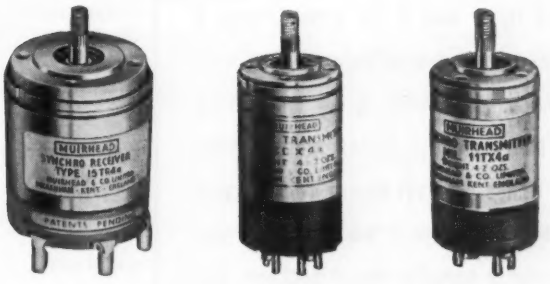

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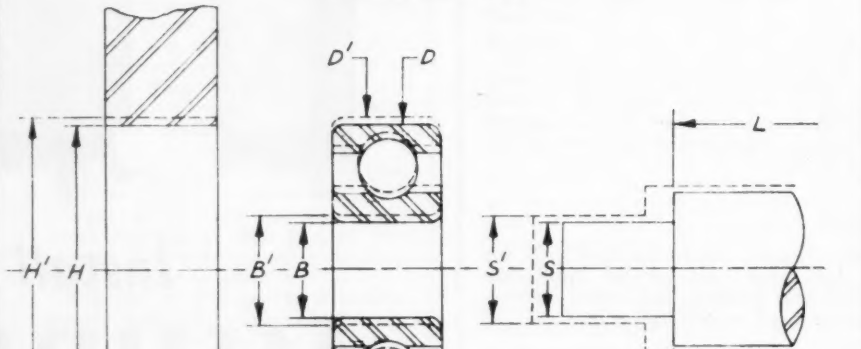
TABLE VIII

Effects of Varying Coefficients of Thermal Expansion On Fits and Radial Play



t_1 and t_2 = Temperature extremes of application

π = Mean Coefficient of Thermal Expansion (t_1 to t_2) Housing

β = Mean Coefficient of Thermal Expansion (t_1 to t_2) Bearing

θ = Mean Coefficient of Thermal Expansion (t_1 to t_2) Shaft

$$H^1 = H + \pi (t_2 - t_1) \quad H = H [1 + \pi (t_2 - t_1)]$$
$$D^1 = D + \pi (t_2 - t_1) \quad D = D [1 + \pi (t_2 - t_1)]$$
$$B^1 = B + \pi (t_2 - t_1) \quad B = B [1 + \pi (t_2 - t_1)]$$
$$S^1 = S + \pi (t_2 - t_1) \quad S = S [1 + \pi (t_2 - t_1)]$$

RELATIONSHIP OF THERMAL COEFFICIENTS OF EXPANSION	FIT OF OUTSIDE DIAMETER	OUTER RING IN	FIT OF BORE	INNER RING	EFFECT OF RADIAL PLAY*
$\pi > \beta = \theta$	Loosen	Slipping	Same	.....	Remains Same
$\pi = \beta > \theta$	Same	.....	Loosen	Slipping	Remains Same
$\pi < \beta = \theta$	Tighten	in Compression	Same	.....	Decreased
$\pi = \beta < \theta$	Same	.....	Tighten	in Tension	Decreased
$\pi > \beta > \theta$	Loosen	Slipping	Loosen	Slipping	Remains Same
$\pi < \beta < \theta$	Tighten	in Compression	Loosen	Slipping	Decreased
$\pi < \beta > \theta$	Tighten	in Compression	Loosen	Slipping	Decreased
$\pi > \beta < \theta$	Loosen	.....	Tighten	in Tension	Decreased

* This column is not correct for the extreme variations between values for mean coefficients of thermal expansion of some of the more exotic materials, but should be taken as a generalization to be validated for each specific combination of materials.

Courtesy Martin-Rockwell

one-piece construction without rivets or other fastening devices. They can support radial and undirectional thrust loads.

Deep groove bearings are generally limited to speeds of DN = 1,000,000 because of the heavier retainer and weakness of fastening devices. They can support radial and thrust loads in either direction but have less capacity than angular contact bearings.

Roller bearings can also be operated at high speed, but in most applications the roller bearing dictates that a deep groove ball bearing be used on the other end of the shaft to take two-directional thrust rather than an angular contact with its greater speedability. Also in many applications the radial clearance of the roller bearing plus the fact that it does not apply thrust to take up clearance in the ball bearing limits ability to balance to close limits.

AFBMA (Anti - Friction Bearing Manufacturers Association) life computations do not take into account centrifugal ball load effects at extreme speed and in cases where DN exceeds 800,000, the life computations become more involved and bearing selection should be confirmed by the bearing manufacturer. Catalog ratings can, however, be used as a guide if bearings are selected conservatively.

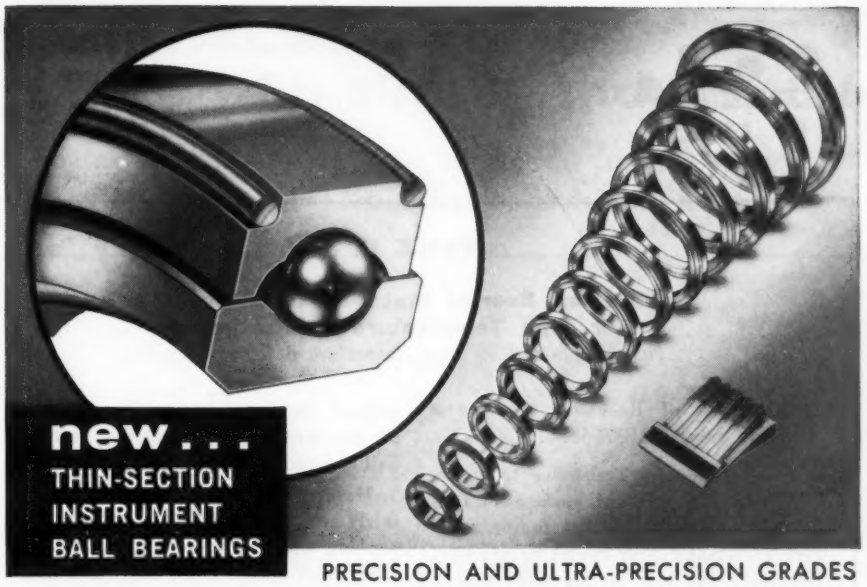
BEARING MATERIALS

Temperature limitations of the materials commercially used in high speed accessory ball bearings are listed in Table X. Generally 440C is satisfactory in most applications over 450 degrees F and is desirable because it is more available and is relatively clean without resorting to vacuum melting. It has less catalytic effect on lubricants and is relatively easy to machine and grind.

Tool steels such as M50 offer more capacity at high temperature because of their better hot hardness. Barden test results and field experiences indicate leaded bronze to be the best retainer material within the temperature limitation of present day lubricants.

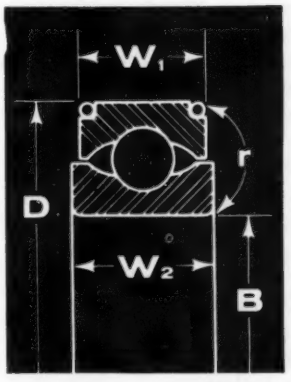
LUBRICATION

At high speed and/or heavy loads, oil must be used to remove heat from



PRECISION AND ULTRA-PRECISION GRADES

TYPE TWF WITH INTEGRAL SHIELDS



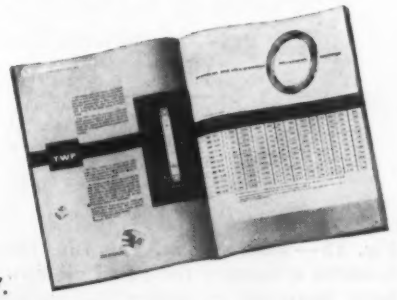
A thin-section radial ball bearing with integral shields on both sides. Deep groove ball races with continuous shoulders, uninterrupted by filling slots. Maximum radial and thrust capacity possible in a radial ball bearing of its dimensions. The close-clearance annulus between shields and inner ring fills with lubricant and functions as an effective seal without the objectionable torque found with contact seals. This design in a precision instrument bearing is possible only with the Split Ballbearing method of construction. Also made in type TWA with alternate balls slightly undersize, for lower torque applications.

Balls and rings are 52100 high chrome alloy bearing steel. Also available in 440 C stainless.

number	*B bore	*D o.d.	W_1 +.000 −.005	W_2 +.000 −.005	Balls no.	Balls size	wt. lbs.	‡L lbs.	§S lbs.
TWF 10-17	.6250	1.0625	.250	.281	24	7/64	.042	276	500
TWF 12-19	.7500	1.1875	.250	.281	24	1/8	.047	354	650
TWF 14-21	.8750	1.3125	.250	.281	27	1/8	.052	375	730
TWF 17-24	1.0625	1.5000	.250	.281	32	1/8	.06	435	870
TWF 21-28	1.3125	1.7500	.250	.281	38	1/8	.07	440	1030
TWF 25-32	1.5625	2.0000	.250	.281	44	1/8	.08	470	1200
TWF 29-36	1.8125	2.2500	.250	.281	50	1/8	.09	490	1360
TWF 33-42	2.0625	2.6250	.250	.281	58	1/8	.14	520	1580
TWF 37-46	2.3125	2.8750	.250	.281	64	1/8	.16	545	1740
TWF 41-52	2.5625	3.2500	.312	.375	48	3/16	.24	1010	2900
TWF 45-56	2.8125	3.5000	.312	.375	52	3/16	.28	1040	3150
TWF 49-62	3.0625	3.8750	.312	.375	58	3/16	.32	1100	3500

Dimensions are in inches. Radius "r" will clear .015" shaft or housing fillet. *Tolerances vary according to size — see catalog 59 for Precision Grade and Ultra-Precision Grade Tolerances. ‡Radial load capacity at 500 rpm and 2500 hours average life. §Static non-brinell load capacity.

send for new catalog 59



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COMPONENTS DIGEST

TABLE IX

Instrument Bearing Material Requirements For High Temperature Application

(as summarized by New Hampshire Ball Bearings, Inc.)

1. Minimum of Rockwell C55 for a thousand hours at 300-600C.

2. Good oxidation resistance to maintain a highly polished surface (1.0 to 3.0 RMS at the operating temperature over a thousand hour operating period). Necessary for low torque and smooth running, as well as to avoid abrasive oxide particles.

3. A high elastic limit (above 250,000 psi) or a high compressive yield strength in the range of 285,000 psi minimum at the operating temperatures over a 1,000 hour period. High elastic limit is necessary to preserve surface finish in raceways and to prevent or minimize amount of plastic working in the surface layers of both the ball and ring materials.

4. Modulus of elasticity between 25×10^6 and 35×10^6 which will remain fairly constant from —55C up to the operating temperature throughout the 1000 hour life. Modulus of elasticity is important in that it determines the size of the contact ellipse at the point of ball to raceway contact.

5. Maintain dimensional stability and a fairly constant coefficient of thermal expansion which will be compatible with other high temperature shaft and housing materials. This requirement is necessary in order that housing and shaft fits remain constant over the operating temperature range, thereby minimizing variations in the bearing internal dimensions. Differences in coefficients of thermal expansion as low as 0.5×10^{-6} "/"/°F make a significant difference in bearing radial play over a 1000F temperature range.

6. That they possess good wear resistance to sliding and rolling friction, maintain freedom from galling, and have a low frictional coefficient.

7. That they exhibit maximum homogeneity of properties, small grain size, freedom from randomly distributed non-metallic inclusions.

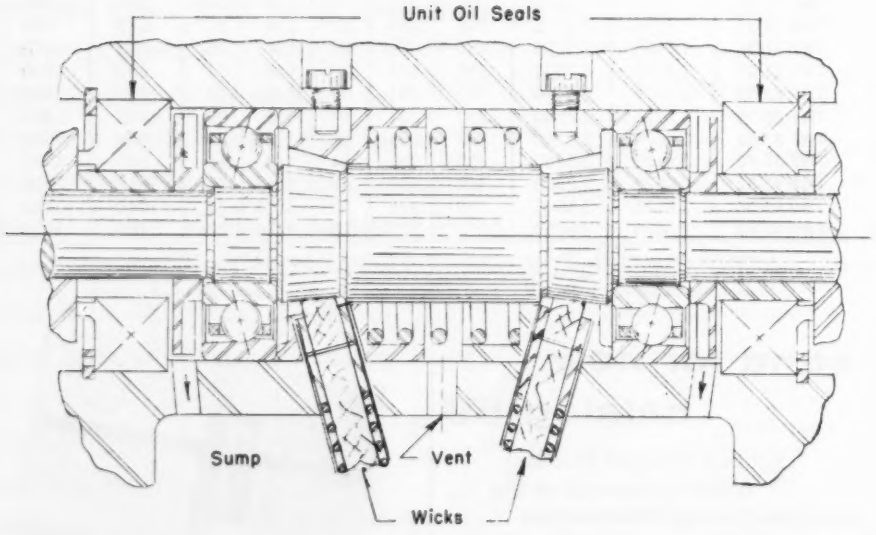


Fig. 13—Wick system. This illustration features symmetry for equal oil flow to both bearings, a spring to maintain thrust on the angular contact bearings, a spring follower to maintain good outer ring alignment serrated slingers to draw oil through bearings (also slingers remove heat from the inner race), and ramps in the spring followers to assure that the oil will go through the bearings. At high speed, oil will leave the shaft tangentially at the wick and will not travel along the shaft.

the balls and retainers as well as to lubricate. Figs. 13 through 15 are illustrations by Barden Corp. showing methods for supplying oil to high speed bearings. Temperature limitations of several lubricants are listed in Table VI. Jet or spray systems permit higher temperature limitations than air-oil mist. This is because at elevated temperatures the air in the mist system oxidizes the oil to form sludge.

Table XII summarizes the design factors and performance of typical high speed applications by Barden Corp.

High Capacity, High Temperature Needle Bearings

The Torrington Co. supplies needle bearings for aircraft applications such as flap track rollers, flying control surface hinges. This type bearing has a high capacity to weight ratio, which makes it very suitable for aircraft type applications. Torrington has set up a high temperature development program to meet new requirements.

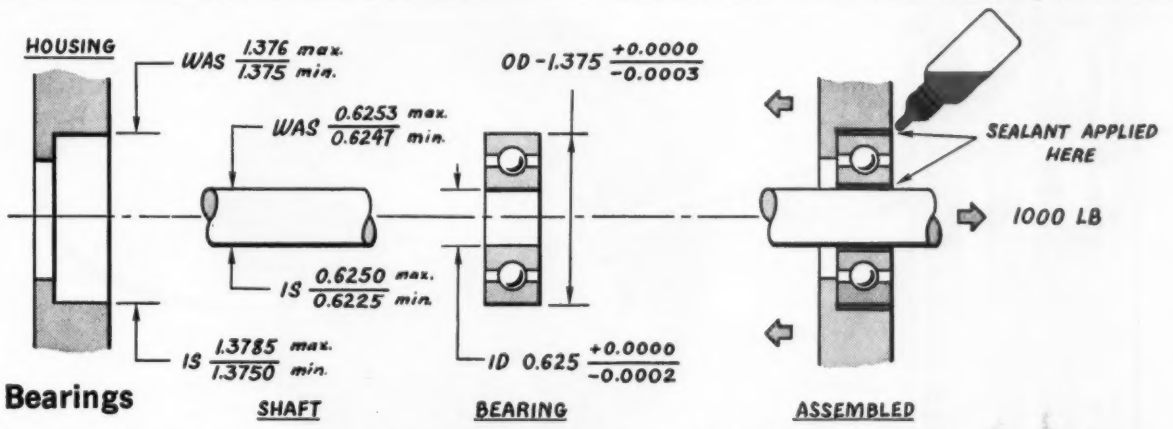
A test rig was designed to test track roller type bearings, that is, bearings which are not housed but are clevis mounted and operate under heavy loads and slow oscillation, the aim being to screen various suitable high temperature materials in the range of 450 to 1200F. It was believed the materials which were found suitable in this manner could be applied to other applications such as rotation of housed bearings, etc. Important material characteristics in the tests included high hardness, good oxidation resistance, high fatigue strength, and good hot hardness.

Room temperature tests of track roller type bearings indicated that 100,000 revolutions of average life could be expected under ideal conditions. That is, an aircraft type bearing, properly lubricated and operating under a load equivalent to 1/3 of its aircraft static capacity, could be expected to last 100,000 revolutions. The aim of the program was to find materials that would perform in a comparable manner under ideal conditions at high temperature.

Fig. 16 by the Torrington Co. shows the results of tests run on a standard stainless steel bearing. Note the point toward the upper right hand corner of the graph labeled 1/3 ASC corresponding to a life of 100,000 revolutions. This point is included to show the optimum room temperature life men-

SIMPLIFY ASSEMBLY...
Retain parts on shafts with slip fit and Loctite

Designing with liquid LOCTITE eliminates press fits, shrink fits, broaching, knurling, keyways, set screws and pinning . . . provides easier tolerances . . . cuts rejects and rework.

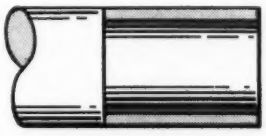


Bearings

LOCTITE Sealant replaced press fit, opening up tolerances .002 inch on shaft and housing. Rejects were cut from 8% to 1% and rework from 20% to 0! Bond to inner race withstands 1000 lbs. thrust . . . equal to the best press fit. Slip fit with LOCTITE gives more uniform retention . . . eliminates fretting damage due to loose "press fit" or bearing distortion resulting from tight press fit . . . assures better shaft alignment. Easier tolerances speed assembly.

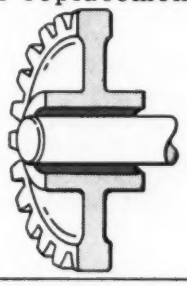
Hardened Sleeves

Eliminates shrink fit . . . mounts hardened sleeve without pulling temper.



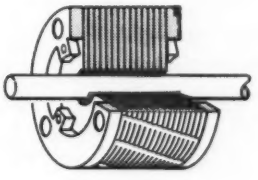
Gears and Pulleys

Eliminates broaching, knurling, shaft distortion. Easier gear replacement.



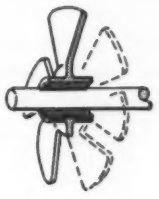
Rotors

Eliminates shaft distortion and resulting regrinding & straightening.



Fans

Eliminates set screws . . . no amount of vibration will loosen part.



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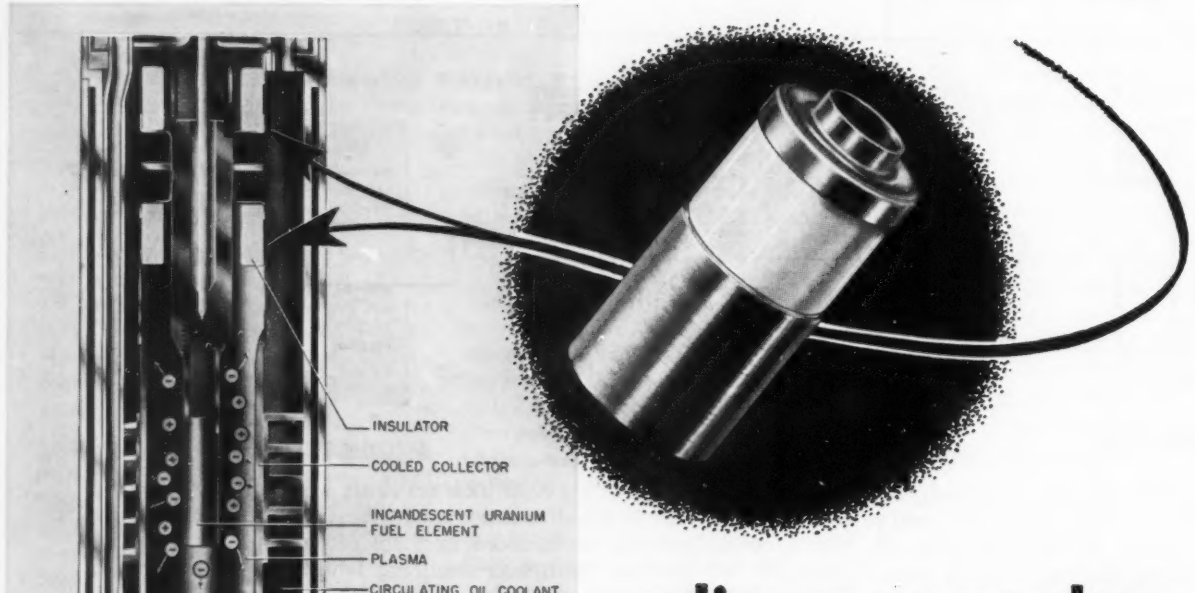

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relies on ruggedness of ALITE® INSULATORS

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488-F

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tioned above. The Texaco Unitemp 500 grease proved best and provided a life very nearly equivalent to the room temperature results. At 600F only one grease appeared suitable, the Shell ETR Type B. At 600° three curves are shown. The one furthest to the left represents bearing operating with no lubrication. The middle curve shows the increase in life which can be obtained with a one-shot lubrication with Shell ETR Type B. The furthest curve to the right marked Shell ETR B shows the further increase in life that can be obtained by periodic relubrication. These three curves indicate the effect of operating a bearing dry at high temperatures, and also show the effect of relubrication. This can be explained since the grease does oxidize over a period of time and, therefore, needs to be replenished periodically. The curve furthest to the left shows the results obtained at 850F with a dry bearing. At this temperature, or for that matter anywhere above 600F, no satisfactory lubricant was found.

Note that the results at 600 and 850F operating dry were very poor. These poor results are explained by oxidation of the basic material and failure through fatigue of the oxide film which is thus formed. The life of the bearings obtained in the grease test were much longer since the lubricant protected the bearing surfaces from oxidation and thereby helped in this manner to improve the life. Secondly, it was determined that the design of the standard type needle bearing would have to be changed in the direction of increased roller diameter and increased bearing internal clearances. Decreased load would also be necessary to provide satisfactory life.

Table XIII (compare with Table X) compares other high temperature materials tested at the specified temperatures with no lubrication. In several cases the 100,000 revolutions of average life were obtained. To obtain this life the applied load was decreased to approximately 15% of the aircraft static capacity. This is approximately ½ of the load which could be applied to a well lubricated room temperature bearing to obtain the same results. One obvious point is that 440C stainless steel is not a very good bearing material for high temperatures. However, when stainless steel is a satisfactory material, it is a wise choice because of its economy. It is readily

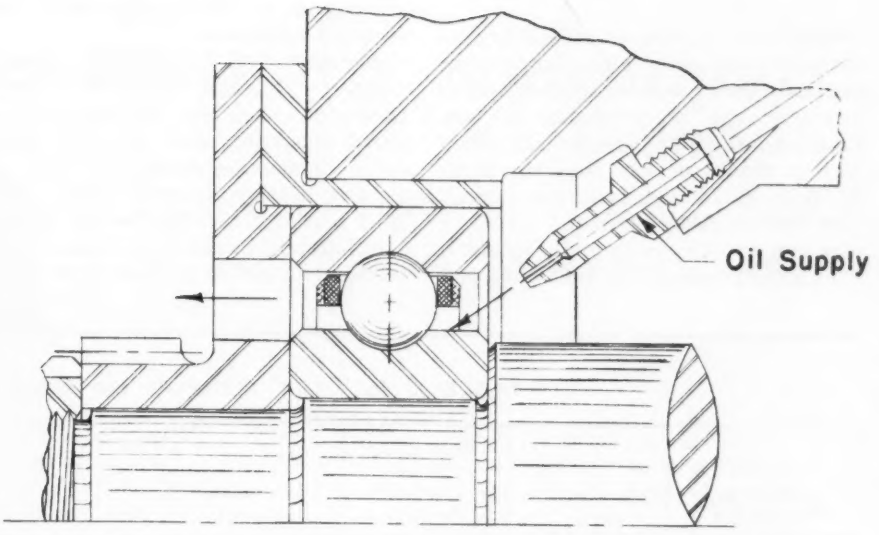

Fig. 14—Jet system. This illustration shows the proper aiming of an oil jet. Note oil is directed to the space between inner race and retainer.

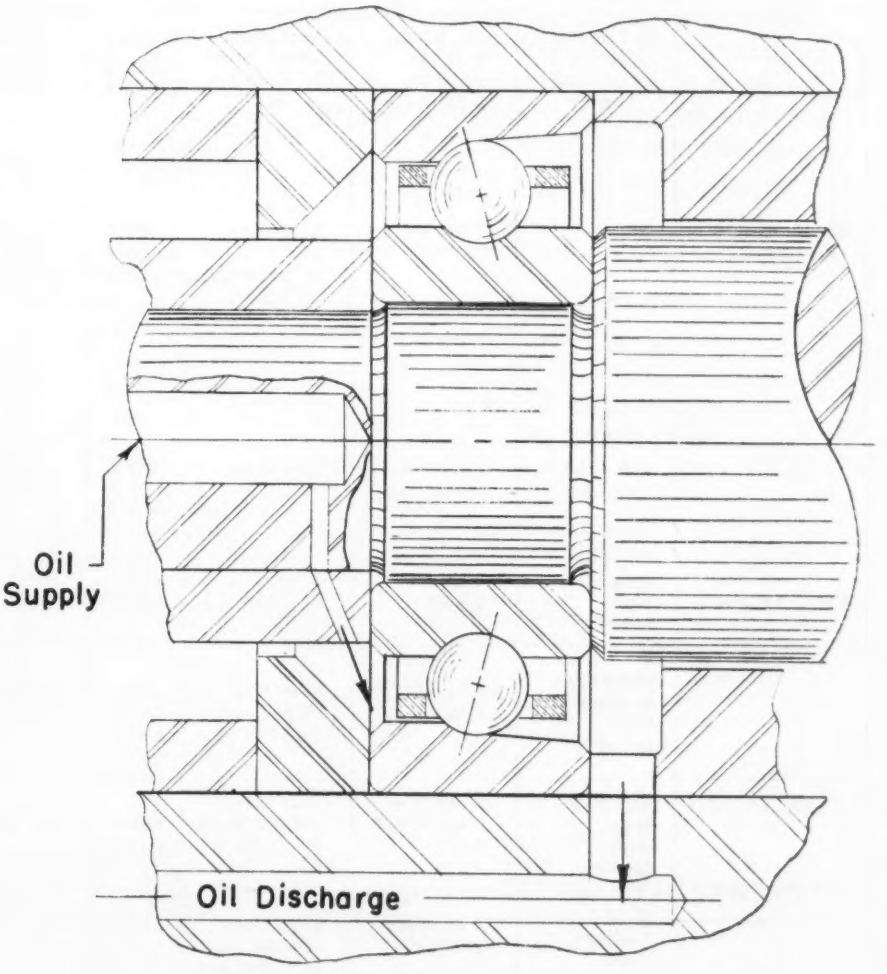

Fig. 15—Oil fed through the shaft. Note how oil is forced to travel through the bearing.

available at a price considerably less than that of other high temperature materials. As a rough comparison, stainless steel can be purchased for approximately $1.00 per pound while various grades of tool steel run from $1.25 to $1.75 and more per pound. The Haynes Alloy #25 and Rene 41 may run to $15 per pound. Ceramics, chrome carbides and stellites often run as much as $35,00 per pound. This basic cost of material plus added cost of manufacturing using these materials indicates that 440C is a wise choice as long as it will operate under the required conditions.

As mentioned above, two requirements for suitable operation of high temperature bearings are increased internal clearances and relatively large roller diameters—approaching that of a roller bearing. Because there would be a need for bearings having low to zero internal clearances and small cross sectional height, a retainer type bearing was tried. For this design, several of the internal clearances could vary through a wide range, at the same time holding radial clearance to a minimum. Although extensive testing has not been done as yet on this type bearing, initial results are shown on Table XIV. The first two graphs from Fig. 16 show the results of unlubricated, stainless steel, full complement bearings at 600 and 850F. The third curve shows the results using a one-shot lubrication of the Shell ETR B. The fourth curve shows the results obtained using the retainer design

TABLE X (a) Materials For Rings And Balls

Operating Temperatures	Steel	Approximate Chemical Analysis Per Cent	Dimensional Change	Hardness at Elevated Temp.		Oxidation Resistance	Notes
				Temp.	Hardness (Rockwell C)		
Up to 250°F	SAE 52100 (Rings) SAE 51100 (Balls)	1C, 1.5 Cr, 0.35 Mn. 1C, 1 Cr, 0.35 Mn.	Less than .0001 in/in in 3000 hrs.	70°F	60 Min.	Excellent	No stabilization heat treatment necessary.
250°F to 450°F	SAE 52100 (Rings) SAE 51100 (Balls)	1C, 1.5 Cr, 0.35 Mn. 1C, 1 Cr, 0.35 Mn.	Less than .0001 in/in in 2500 hrs. at 300°F.	70°F 350°F 450°F	58 Min. 56 Min. 54 Min.	Good	All parts stabilized in accordance with FS-136.
	DHA	0.9C, 1.5 Cr, 1.5 Mn.	Less than .0001 in/in in 2500 hrs. at 300°F.	70°F 350°F 450°F	58 Min. 57 Min. 56 Min.	Good	All parts stabilized. —— When given a stabilizing heat treatment, 51100, 52100, and DHA are suitable for many applications in the 350-450°F range: however, they are not as stable dimensionally as they are at temperatures below 350°F. If utmost stability is required use materials in 450-600°F group below.
450°F to 600°F	AISI 440C Stainless	1C, 18 Cr, 1 Mn, 1 Si.	Less than .0001 in/in in 1200 hrs.	70°F 450°F 600°F	58 Min. 55 Min. 52 Min.	Excellent	As heat treated for maximum hardness at elevated temperatures.
	AISI M-2 Type High Speed	6Mo, 5 W, 4 Cr, 2 V, 0.8 C.	Less than .00005 in/in in 1200 hrs.	70°F 450°F 600°F	63 Min. 61 Min. 60 Min.	Good	Recommended where stability and high hardness at these temperatures is required.
	M-50 Type Medium High Speed	4 Cr, 4Mo, 1 V, 0.8 C.	Less than .00005 in/in in 1200 hrs.	70°F 450°F 600°F	62 Min. 59 Min. 57 Min.	Good	May be used where tungsten is not permitted.
600°F to 800°F	AISI M-2 Type High Speed	6 Mo, 5 W, 4 Cr., 2 V, 0.8 C.	Less than .00005 in/in in 1200 hrs.	800°F	57 Min.	Fair	As measured at 800°F M-2 oxidizes at ½ the rate of 52100 steel.
	M-50 Type Medium High Speed	4 Cr, 4 Mo, 1 V, 0.8 C.	Less than .00005 in/in in 1200 hrs.	800°F	54 Min.	Fair	Comparable to M-2 in oxidation resistance at 800°F. Recommended where use of Tungsten must be avoided.
800° and Higher	Bearings can be made of special materials for operation in this temperature range.						Courtesy Fafnir Bearing Co.

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(NULL VOLTAGE) (FUND)	± 7 + j15
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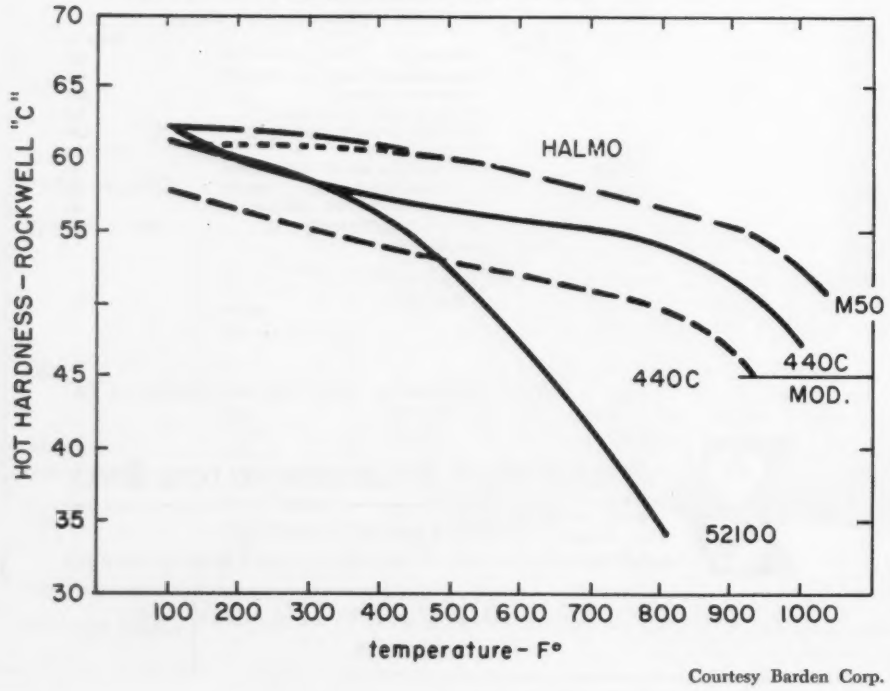
TABLE X (b)
Materials for Retainers, Shields, and Seals

Operating Temperatures	Materials Retainers	Shields and Seals	Notes
—67°F to 300°F	Grade L Phenolic Resin Laminate AISI-C1008 pressed steel Machined brass or bronze	AISI-C1008 pressed steel shield Buna N seal (with standard fabric) Hycar PA seal (with Dacron fabric)	Only special laminates of Grade L can stand temperatures above 250°F continuously, and their availability is limited. Pressed steel retainers are used in bearings under light to medium loads. Buna N gets brittle above 250°F except for very short exposure times. Frequently it is an effective seal above 250°F but if brittle is destroyed on removal. Teflon decomposes slowly at 400°F and fast at 600°F. It is destroyed on removal due to mechanical change.
300°F to 450°F	Special Grade L Phenolic Resin Laminate AISI type 430 or 305 pressed stainless steel AISI-C1008 pressed steel Machined Iron-Silicon Bronze	AISI type 430 or 305 pressed stainless steel shield Silicon rubber seal (with glass fabric) Teflon seal (with glass fabric)	
450°F to 600°F	Machined Iron-Silicon Bronze AISI type 430 or 305 pressed stainless steel	AISI type 430 or 305 pressed stainless steel shield Teflon seal (with glass fabric)	**Approximate Chemical Analysis, percents (major elements)** AISI-C1008 0.1C Max., 0.4 Mn, Bal. Fe AISI 430 0.12C, 1.0 Mn, 16 Cr, Bal. Fe, 1.0 Si. AISI 305 0.12C, 2.0 Mn, 11.5 Ni, 18 Cr, Bal. Fe, 1.0 Si Machined Bronze 60 Cu, 38 Zn. Iron Silicon Bronze 1.5 Fe, 3.0 Si, 90 Cu, Bal. Zn. Ni-Resist 3.5C, 20 Ni, 2.0 Cr, 68 Fe, 6.0 Cu.
600°F to 800°F	Machined Iron-Silicon Bronze AISI type 430 or 305 pressed stainless steel S-Monel and heat resistant nodular cast irons (Ni-Resist)	AISI type 430 or 305 stainless steel shield	

Courtesy Fafnir Bearing Co.

TABLE X (c)
Hot Hardness Vs. Temperature Of Common Bearing Materials
(After ½ hour at temperature)



Courtesy Barden Corp.

TABLE XI
General Rules For High Speed High Temperature Operation.

1. Be sure the bearing has enough radial play to allow for radial expansion of the shaft with respect to the housing. Allow at least .0005 + [(O.D. + Bore) /2] x 7 x 10^{-6} x ΔT, where ΔT is anticipated temperature rise of shaft over housing.
2. Do not solidly preload one bearing against another. Centrifugal ball loads and differential expansion almost invariably lead to failure with solid preload.
3. Balance to close limits. Unbalance loads must be included in life calculations and generally should be less than 1/10 of the load rating at speed.
4. Watch out for critical speeds in the operating range. Bearings will run at or near a shaft critical provided the critical is at a low speed, or if time at critical is short. The effect of operation at critical speed on bearing performance is unpredictable however, and it is therefore best to keep it well above the operating speed even though with a good design, it is sometimes scarcely noticeable.
5. Spring preload is normally recommended. It should be around 1/3 to 1/4 the bearing capacity at speed.

Courtesy Barden Corp.

Jet brake cup — LS-53
Synthetic lube diaphragm — LS-53
Diesel equipment seal — Viton
Drop-off tank seal — LS-53
Chemical pump liner — Viton
Natural gas valve diaphragm — Viton

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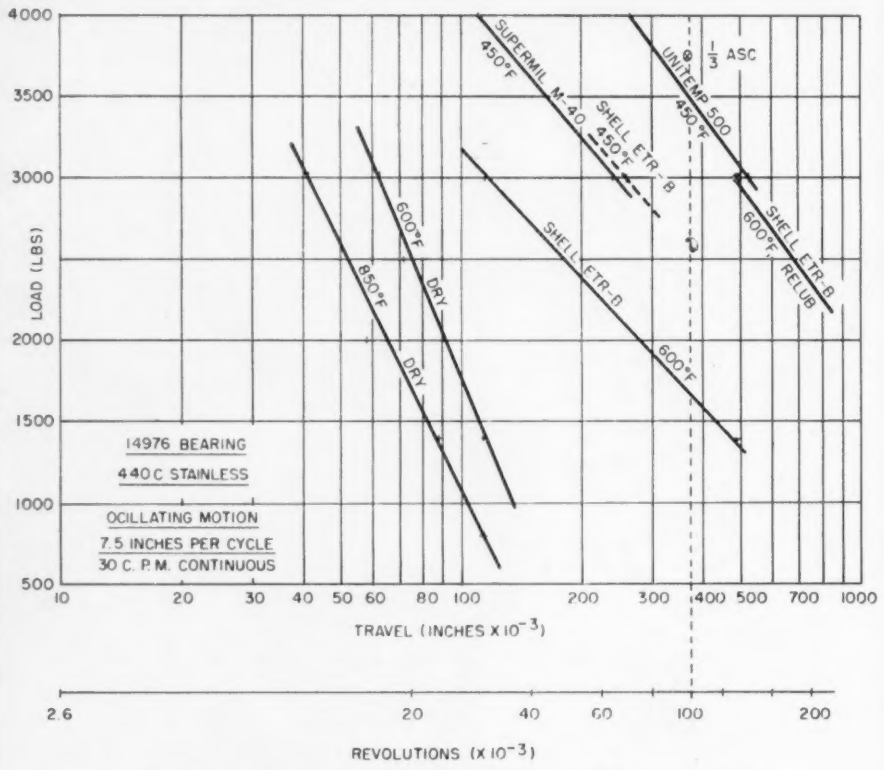

Fig. 16—Effect on life temperature, lubrication, and load.

TABLE XII

Typical Case Histories At High Speed, High Temperature

BASIC BEARING	SPEED RPM	DN/10⁶	TEMP. °F.	LUBRICANT	RAD. LOAD (lbs.)	THRUST LOAD (lbs.)	AVG. LIFE (Hrs.)	
S100HJB6	100,000	1.0	400	Plexol 201	80	80	110	Test Unit
S100HJB6	140,000	1.4	400	Plexol 201	..	20	490	Test Unit
S100NA5	100,000	1.0	400	Plexol 201	..	15	480	Test Unit
S100HJA6	110,000	1.1	470	MIL-L-6085	40	50	200 +	Turbo Compressor
S101HJB6	110,000	1.3	500	L825	20	30	100 +	Air Turbine Test
S101HJB6	65,000	0.8	625	DC 710	15	30	100 +	Air Turbine Test
S101HJB6	55,000	0.65	380	MIL-L-6085	25	45	100 +	Air Turbine
S103HJA6	30,000	0.5	500	MIL-L-6085	20	50	100 +	Air Turbine
S104HJA5DT	70,000	1.4	540	MIL-L-7808	0 80	40 550	1000 + starts	Starter
S200HJ6	80,000	0.8	400	MIL-L-7808	20	50	100 +	Air Turbine
S205NA6	40,000	1.0	300	MIL-L-15016 or 2075	50	310	200 +	Gas Turbine
38HJ6	105,000	0.84	350	MIL-L-6085	15	50	100 +	Air Turbine
104HJB5	95,000	1.9	350	MIL-L-7808	..	1243	600 + starts	Starter
202HJA6DT	40,000	0.60	340	MIL-L-6085	25	250	100+	Air Turbine
203HJA6DT	41,000	0.70	350	MIL-L-6085	25	300	100+	Air Turbine
101HJ6	70,000	0.85	350	MIL-L-6085	15	20	75 +	Air Turbine
100HJ6	100,000	1.0	400	MIL-L-6085	25	80	100+	Air Turbine

D = Bore Diameter
N = RPM

Courtesy Barden Corp.

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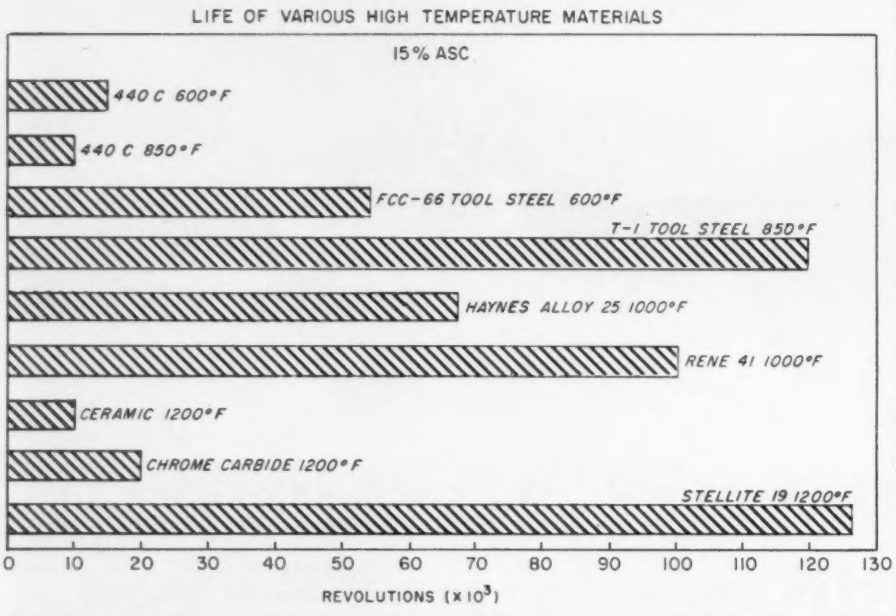
COMPONENTS DIGEST

Courtesy Torrington Co.

TABLE XIII

Life of Various High Temperature Materials


LIFE OF VARIOUS HIGH TEMPERATURE MATERIALS
15% ASC
440 C 600°F
440 C 850°F
FCC-66 TOOL STEEL 600°F
T-1 TOOL STEEL 850°F
HAYNES ALLOY 25 1000°F
RENE 41 1000°F
CERAMIC 1200°F
CHROME CARBIDE 1200°F
STELLITE 19 1200°F
0 10 20 30 40 50 60 70 80 90 100 110 120 130
REVOLUTIONS (x 10³)

operating with no lubrication. On the last graph are the results of the same bearing operating dry with several of the parts silver plated. These tests indicate much longer life with the retainer type bearings.

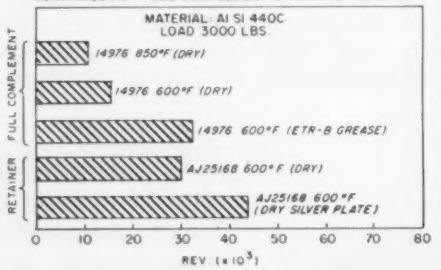
In designing a high temperature bearing having small cross sectional height, a basic requirement is for a material of very high oxidation resistance. This is necessary since failure of the stainless steel type bearings occurs through fatigue of the oxide film, subsequent flaking, and choking of the bearing. This is much more severe in bearings having small diameter rollers than in bearings having large diameter rollers. Therefore, this oxidation and oxide fatigue must be eliminated to make a bearing having small cross sectional area. Haynes Alloy #25 design has been used successfully to 1200F, other materials might do as well.

In summarizing design factors of bearings at elevated temperatures, the Torrington Company says the bearing material is of major importance. Stainless steel forms a brittle oxide film which tends to fatigue and flake off the bearing surfaces under heavy rolling loads. Such is not the case with many other high temperature materials having better oxidation resistance. Many of the super alloys form a thin but tough oxide film which appears to protect the bearing surfaces and, also to some extent lubricate them. This seems to be true since in many cases it is impossible to operate these super alloys at low temperatures. As an example, Haynes Stellite #19 was tested at 850, 1000 and 1200F under identical conditions. At both 850 and 1000F, the material did not stand up as well as it did at 1200F and longer life could easily have been obtained with some other less expensive material. Results such as this have pointed out the fact that in some cases a thin film of oxide is actually a benefit to a long bearing life.

TABLE XIV

Comparison of Full Complement And Retainer Bearings

Courtesy Torrington Co.



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Magnetic materials for high temperature components, and a survey of problems and developments in hi-temperature pots.

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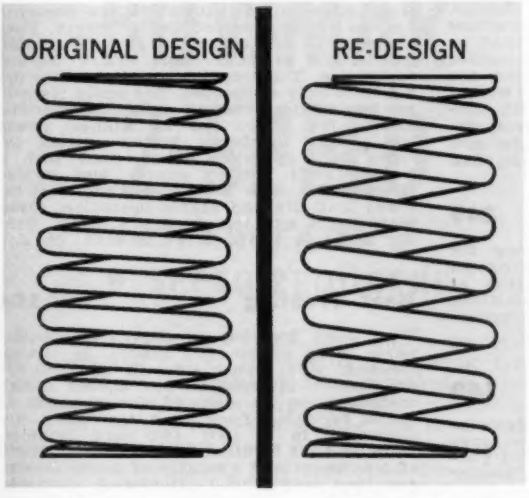

10 coils—.120″ wire
130 lbs. of wire per
1M springs

7 coils—.105″ wire
60 lbs. of wire per
1M springs

Because of mounting cost conditions, a user of motor-support springs asked for a complete design check. Redesigned by A.S.C. engineers, required stresses were met by a slight change in wire size, allowing a reduction in number of coils from 10 to 7. This meant a saving of 70 pounds of material per thousand springs. Because of the shorter length of wire, coiling and grinding speeds were increased, heat-treating time reduced. Saving to the customer—40%.

How about the springs you use? A consultation on your specifications costs you nothing. Just contact any Division of Associated Spring Corporation. For a handy reference to spring action, write for "Spring Design and Selection—in brief."

Associated Spring Corporation

General Offices: Bristol, Connecticut

Wallace Barnes Division, Bristol, Conn. and Syracuse, N. Y.
B-G-R Division, Plymouth and Ann Arbor, Mich.
Gibson Division, Chicago 14, Ill.
Milwaukee Division, Milwaukee, Wis.
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Seaboard Pacific Division, Gardena, Calif.
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CIRCLE 74 ON INQUIRY CARD

For Your 3-Ring Binder

NEW DATA SHEETS

For your free copy of the data sheets listed on this page, circle the appropriate number of the item on the Inquiry Card.

Phenolic Molding Compounds 195

Technical bulletin lists chemical resistance of seven Bakelite phenolic molding compounds to acids, alkalies, solvents and common mixtures. Information will be of special significance to designers contemplating use of phenolics in applications where corrosion is a serious problem. Union Carbide Plastics Co., New York, N.Y.

Card Receptacle And Socket 231

Catalog gives complete technical information on receptacles, plugs, paired plugs with shell, card receptacles, card plugs, plugs with shell, cable plugs and printed circuit card receptacle locking devices. These card receptacles and sockets are designed for switch gear, computers, instruments, telephone panels, airborne communications equipment, guidance systems, telemetering equipment and other automatic control devices using printed circuitry for military and commercial applications. Methode Manufacturing Corp., Chicago, Ill.

Solid State Power Control 193

A new line of power control units using magnetic gating amplifiers driving silicon controlled rectifiers is described in an 8 page brochure. The devices, designed for proportional or switching control, are used for both 60 and 400 cps systems, and are said to satisfy 95% of power control requirements. Details given in the brochure include circuit operation of the units and illustrations of transfer characteristics, unit schematics, and typical servo systems employing the power control units. Magnetic Amplifiers, Inc., N. Y., N. Y.

Acoustic Noise Generator 174

Four-page bulletin describes a new acoustic noise generator that uses an electro-mechanical transducer of moving-coil type producing 166 db of random noise and 170 db at discrete frequencies. Specifications, performance characteristics and typical frequency response curves are given. Avco Res. & Advanced Development Div, Wilmington, Mass.

Hydraulic Flow Regulators 197

Pressure-compensated hydraulic flow regulating valves have a cartridge style design that permit greater weight and space savings. Pressure ratings are up to 3000 psi and control flow rate is independent of system pressures or varying back pressures. 4 page bulletin contains performance standards and general design data. Waterman Engineering Co., Evanston, Illinois.

Wide Range Ohmeter 198

Wide range ohmeter measures resistance in the range of 50 milliohms to 5,000 megohms applying only 30 millivolts maximum to the sample. Two page bulletin gives specifications and includes application data on measurement of forward and back resistance of semiconductors, thermistors, low resistance copper paths, and moving coils in electrical indicating instruments. Mid-eastern Electronics, Inc., Springfield, N.J.

Fail-Safe Annunciator 178

Annunciator uses 2 lamps per annunciator point, one to signal field abnormality and one to signal its own component failure. Bulletin contains complete description and operation details. Panalarm, Div. of Panellit, Inc., Skokie, Illinois.

Variable Resistors 199

¾"-diameter, highly reliable, low-cost, miniature, preset, wirewound, variable resistors have a resistance range of ½ to 500 ohms linear taper only. Standard tolerance is ±20% with ±10% tolerance available in most resistances at extra cost. Data sheet contains complete electrical and mechanical specifications and dimensional drawings. Chicago Telephone Supply, Elkhart, Ind.

Exploding Bridgewire System 196

Operating principles of an exploding bridgewire system are presented in a 6 page brochure. Diagrams, performance details, and photographs of various configurations of the system for rocket motor initiation, missile stage separation, missile destruction upon command, and warhead initiation are provided. Design data comparing the weight requirements of the new system with conventional detonation systems is given enabling engineers to evaluate weight and space savings Librascope, Sunnyvale, Cal.

Materials Research Furnace 249

High-temperature resistance furnace for use in materials research and development is designed for continuous operation at temperatures up to 4,800F or intermittent use at temperatures up to 5,100F. Curtiss-Wright Corp., Goleta, Cal.

Electronic Galvanometer 149

A new bulletin presents a complete description of the operating characteristics, specifications and applications of a multi-purpose electronic galvanometer. Chopper stabilized, the instrument can be used for current measurements to 2×10^{-11} amperes. It is 20 times as sensitive as the mechanical mirrored-type galvanometer and its all-transistor construction makes it much more rugged. KinTel Div. of Cohu Electronics, Inc., San Diego, Cal.

Magnetic Tape 179

Magnetic tape, for digital and analog recording, features a unique magnetic coating, micro-polishing and extra-precise slitting. 4-page bulletin includes performance qualities and specifications. Consolidated Electrodynamics Corp., Pasadena, Cal.

Electronic Connectors 201

Environmentally-sealed miniature electronic connectors are vibration and moisture-resistant and are designed to be completely interchangeable with other miniature connector styles. Design features surpass all requirements for miniaturizing programs and tests exceed MIL-C-26482. Catalog insert gives complete specifications and lists available contact arrangements. Burndy Corporation, Toledo, Ohio.

Miniature Rotary Switches 177

Data is given on lever-actuated and solenoid-operated switches that permit a wide variety of remote-control applications. The bulletin also contains complete descriptions of the basic miniature rotary selector switch, including dimensions, mounting data, and electrical ratings. Electro Switch, Weymouth, Mass.

Shock Mounting 222

Data sheet explains and gives suggested new approaches for lower cost shock mounting cathode ray, memory or data storage tubes within non-shock sensitive and non-retentive magnetic shields. Magnetic Shield Division, Perfection Mica Co., Chicago, Ill.

Bobbinless Resistors 225

The "bobbinless" precision wire wound resistor, a new concept in resistor technology, is described in a new brochure containing complete details and specifications. By eliminating the bobbin and floating the resistive element in a special viscous fluid, the truly strain-free resistor offers unusual stability and reliability. General Transistor Corp., Jamaica, New York.

Sub-Miniature Fuses 228

Data sheet gives complete technical information on sub-miniature fuses known as Microfuses. Featuring close resistance tolerances and high reliability in quick blowing characteristics, the fuse can be used in circuits with voltages up to 125 v and currents up to 200 amps. Littlefuse, Inc., Des Plaines, Ill.

Audio Signal Transistor 209

Germanium alloy transistors are designed for use as single-ended audio drivers. They are capable of dissipating 300 mW at 25C and 50 mW at 75C because of low thermal resistance. The transistor and the case are not internally connected. The audio transistor has a linear current gain characteristic giving low distortion at higher power levels. The maximum voltage rating insures safe operation when used with a 6- or 12volt battery supply and welded construction with a vacuum-tight seal insures long life and stable operation. Complete specs and test data are given. Bendix Aviation Corp., Long Branch, N. J.

Heat Treating 194

Why heat treating of thermostat metal parts, even simple flat blades, is recommended; what cause stresses and the redistribution of stresses; and should design compensation be allowed for changes in shape resulting from heat treatment are discussed in a new two-page bulletin. Data on heat treating temperatures, length of treatment and quantity of parts treated per load is included. Metals & Controls, Div. Texas Instruments, Inc., Attleboro, Mass.

Precision Counters 219

Complete technical details are given on simplified design bi-directional precision degree and mil counters which have no transfer masks or shade and no interrupted gearing to complicate operation. The units do not count in multiples of 10, but in hours, degrees, mils, minutes, etc., return to zero and repeat. Chicago Dynamic Industries, Inc., Precision Products Division, Chicago, Ill.

Hermetic Connectors 191

How to install hermetic connectors is described in a new technical report. Included is a step-by-step procedure for fusing hermetic connectors to plates, boxes or cans—from pre-heating through the finished soldering—plus details on how to protect the connector during the fusion process. Deutsch Co., Electric Components Div., Banning, Cal.

(Continued on page 88)

WASTING SPACE AND ADDING EXTRA POUNDS *IN TUNING, POSITIONING AND SCANNING SYSTEMS*

USE

BOWMAR 2-SPEED

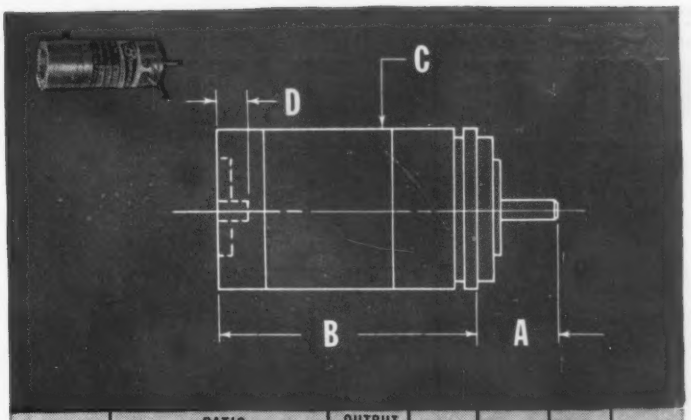
- **GEARHEADS**
- **SPEED REDUCERS**

Bowmar single-unit 2-speed gearchangers can reduce the weight and size of any control package or system which requires or which could be improved by multi-speed operation. Such systems typically include those which may benefit from fast slewing and slow zeroing. These Bowmar gearchangers permit extremely fast system dynamic response, plus slow fine-tune modes of operation which reduce inertial hunting effects.

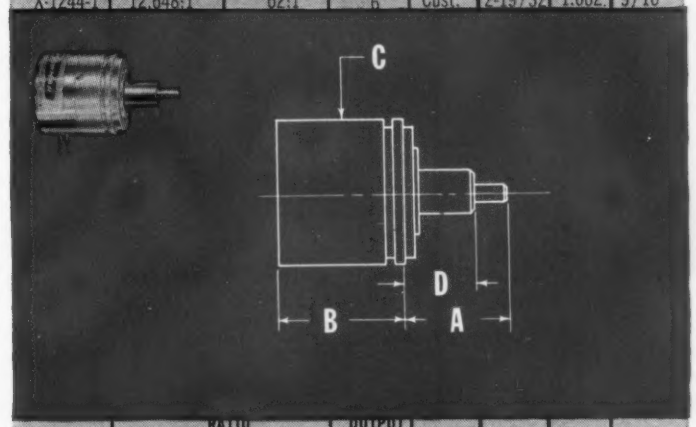
Scarcely larger than a gearhead or speed reducer alone, Bowmar's new gearchangers are electrically operated and are completely self contained. They eliminate the need for outboard mechanisms, extra mounting plates and "accident prone" shifting complexes.

Bowmar produces these precision gear changers in sizes from 11 to 23, in all ratios and ratio differentials. Units shown are representative of a few Bowmar types.

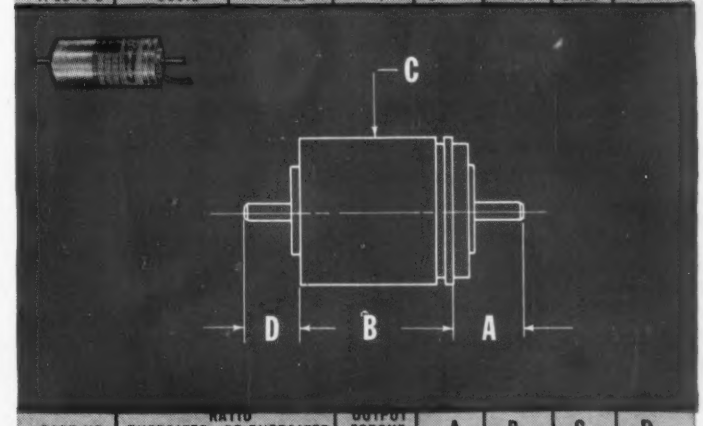
Send for Data Package 1159



PART NO.	RATIO ENERGIZED	RATIO DE-ENERGIZED	OUTPUT TORQUE (IN.-OZ.)	A	B	C	D
X- 801-1	36,600:1	20:1	6	3/8	3-11/32	1.437	9/16
X- 863-1	8:1	*1:1	3	7/16	2.000	1.062	7/16
X- 924-1	470,000:1	320:1	24	11/16	3-11/32	1.437	7/16
X- 989-3	42,978:1	26:1	5	5/8	2.450	1.062	7/16
X- 709-1	24,000:1	2,400:1	6	5/8	2.450	1.062	7/16
X- 740-1	10,000:1	100:1	6	11/16	2.376	1.437	7/16
X-1244-1	12,648:1	62:1	6	Cust.	2-19/32	1.062	9/16



PART NO.	RATIO ENERGIZED	RATIO DE-ENERGIZED	OUTPUT TORQUE (IN.-OZ.)	A	B	C	D
X- 637-1	6:1	*1:1	16	.860	1.062	1.500	.563
X- 691-3	50:1	*1:1	10	1	2.058	1.750	5/8
X- 853-1	135:1	*1:1	5	1-3/32	1.994	1.437	23/32
X- 853-2	10:1	*1:1	5	1-3/32	1.994	1.437	23/32
X-1240-1	18,500:1	50:1	4	1.132	2.750	1.437	.632
X-1240-2	5,000:1	50:1	4	1.132	2.750	1.437	.632
X-1343-3	300:1	*1:1	4	1	1.750	1.437	9/16



PART NO.	RATIO ENERGIZED	RATIO DE-ENERGIZED	OUTPUT TORQUE (IN.-OZ.)	A	B	C	D
X- 748-1	36,600:1	20:1	4	1/2	2.215	1.062	15/32
X-1008-1	36:1	*1:1	8	11/16	1-17/32	1.437	9/16
X-1008-2	1,463:1	*1:1	8	11/16	1-17/32	1.437	9/16

*Running torque dependent upon input torque or load of equal value.

BOWMAR INSTRUMENT CORPORATION

8000 BLUFFTON ROAD • FORT WAYNE, INDIANA

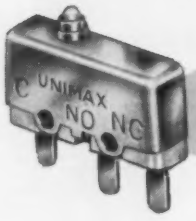
Precision Electromechanical Controls and Instrumentation, Servomechanisms
Precision Miniature Gearheads, Navigational Counters, Indicating Devices

CIRCLE 75 ON INQUIRY CARD

SUBMINIATURE

HIGH-TEMPERATURE SWITCHES

for continuous full-load service at high ambient temperatures.



650°F

FC-1
Full electrical rating applies from −65 to +650F. Metal cover, Mycalex base, welding-tab or threaded-stud terminals.

400°F

USM4
Case and button molded of heat-resistant material; stainless-steel operating mechanism.

275°F

USM5
Meets MIL-S-6743 and Military Drawing MS-25085.

ELECTRICAL RATING
single-pole double-throw

FC-1 4 amp. 18-30 v.d-c, resistive
2.5 amp. 18-30 v.d-c, inductive

USM4 5 amp. 125/250 v.a-c
5 amp. 30 v.d-c, resistive
3 amp. 30 v.d-c, inductive

USM5 5 amp. 125/250 v.a-c
5 amp. 30 v.d-c, resistive
3 amp. 30 v.d-c, inductive

Ask for Catalog 159A.

UNIMAX SWITCH
Division, The W. L. Maxson Corporation
IVES ROAD, WALLINGFORD, CONNECTICUT

CIRCLE 61 ON INQUIRY CARD

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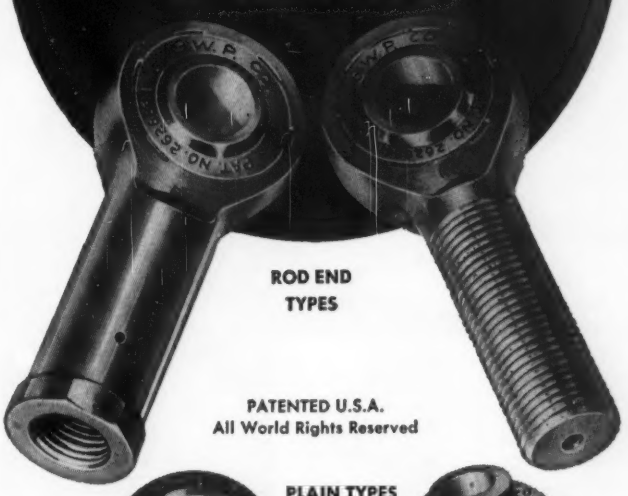
*See Previous Issue

SOUTHWEST

"Monoball"®

SELF-ALIGNING BEARINGS



ROD END TYPES

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PLAIN TYPES

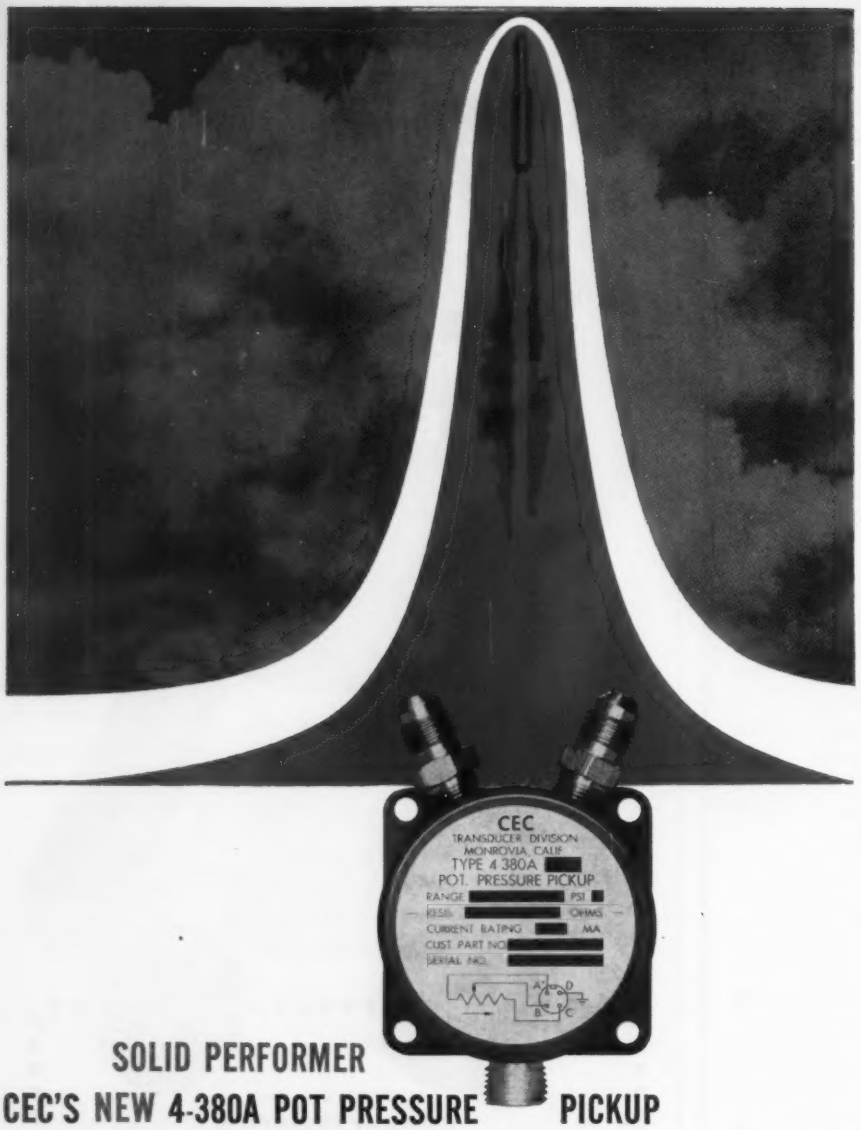
CHARACTERISTICS

	ANALYSIS	RECOMMENDED USE
1	Stainless Steel Ball and Race	For types operating under high temperature (800-1200 degrees F.).
2	Chrome Alloy Steel Ball and Race	For types operating under high radial ultimate loads (3000-893,000 lbs.).
3	Bronze Race and Chrome Steel Ball	For types operating under normal loads with minimum friction requirements.

Thousands in use. Backed by years of service life. Wide variety of Plain Types in bore sizes 3/16" to 6" Dia. Rod end types in similar size range with externally or internally threaded shanks. Our Engineers welcome an opportunity of studying individual requirements and prescribing a type or types which will serve under your demanding conditions. Southwest can design special types to fit individual specifications. As a result of thorough study of different operating conditions, various steel alloys have been used to meet specific needs. Write for Engineering Manual No. 551. Address Dept. EMD-59

SOUTHWEST PRODUCTS CO.
1705 SO. MOUNTAIN AVE., MONROVIA, CALIFORNIA

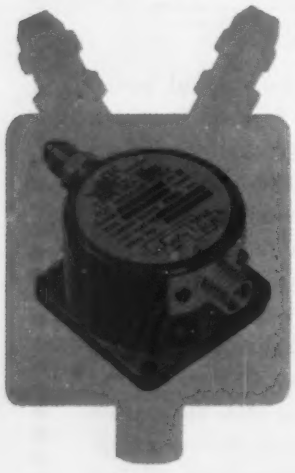
CIRCLE 81 ON INQUIRY CARD



SOLID PERFORMER

CEC'S NEW 4-380A POT PRESSURE PICKUP

Now with a redesigned flexure support system, the 4-380A sets a new standard of performance for low-pressure potentiometer pressure transducers. The 4-380A is unequalled for resistance to shock and vibration. Most pressure ranges are capable of continuous exposure to 25 g vibrations up to 2 KC for periods up to several hours with negligible change in calibration.



Pressure ranges are available from ±1 psi to 100 psi. Absolute, gage, and differential models are offered. Operating over the temperature range from −65° F to +200° F, most pressure ranges exhibit temperature effect of less than one percent. The unique construction of the 4-380A keeps the measured fluid external to the mechanical and electrical system. In absolute models, the internal mechanisms are enclosed within the evacuated chamber. For detailed specifications, call your nearest CEC sales and service office, or write for Bulletin CEC 1604-X21.

Transducer Division CEC

CONSOLIDATED ELECTRODYNAMICS / 360 sierra madre villa, pasadena, california

CIRCLE 78 ON INQUIRY CARD

Pneumatic Transducer **187**

Designed for highly sensitive and accurate linear conversion of a varying d-c volt or milliamp signal to a pneumatic signal, a specially constructed transducer provides linear accuracy even at the low output range of 1.5 psig. Bulletin explains the principle of operation and contains pneumatic and electrical rating specs, performance data, and special features. Associated Control Equipment, Inc., Coraopolis, Pa.

Time Delay Relays **163**

Eighteen standard time delay relays are shown in an 8-page bulletin. Factory preset, internally adjustable and externally adjustable units are described. Delayed pull-in, delayed drop-out maintained, and delayed drop-out momentary operations are available. All relays are small, lightweight, and offer delay times from 50 milliseconds to 50 seconds. Units meet mil specs. Master Specialties Co., Los Angeles, Cal.

Phosphor Bronze Rod **181**

Technical data is available on phosphor bronze rod which is an alloy of copper, lead, tin, and zinc and is particularly adapted to applications requiring corrosion resistance, strength, electrical conductivity, antifrictional properties, low temperature performance, or non-magnetic characteristics. Complete alloy data including physical, mechanical and fabricating properties and common fabrication processes are included as part of the bulletin. Bridgeport Brass Co., Bridgeport, Conn.

Digital Tape Handler **183**

A versatile, dual-speed, digital read/write tape handler for on-line or auxiliary application, providing maximum utility at a moderate price, records binary output from various conversion devices, and can also record output directly from digital transducers or other data sources. Eight page booklet includes complete specifications on units which are available with ½, ¾, or 1 inch tape, providing up to 32 data channels. Ampex Corp., Redwood City, Cal.

Varnish Selector **182**

A handy reference chart for engineers and designers identifies the major types of insulating varnishes and magnet wire enamels by thermal classification. With it you can determine the insulating varnish which will provide the best combination of thermal, electrical and mechanical properties when applied over the magnet wire you have selected. Schenectady Varnish Co., Schenectady, N. Y.

Pulse And Current Generators **180**

Two bulletins contain complete specifications for a magacycle pulse generator and two models of millimicrosecond current generators which feature extreme versatility of performance and application through modular plug-in design. All pulse parameters of the pulse generator are continuously variable over a wide range with excellent control resolution and high stability. The 2 channel and 4 channel current generators provide fast rise time, high power, current pulse outputs. Electro-Pulse, Inc., Culver City, Cal.

High-Vacuum Pump **208**

A bulletin describes a small permanent-appendage electronic high-vacuum pump that can be integrated into a wide range of electronic devices for the removal of micro amounts of gas. A power supply designed to operate the pump is also described. Specifications and a pressure vs. current chart are included. Ultek Corp., Palo Alto, Cal.

CIRCLE 79 ON INQUIRY CARD →

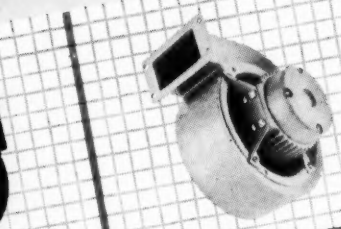
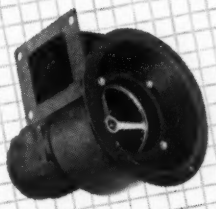
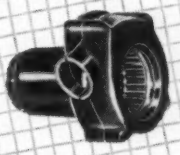
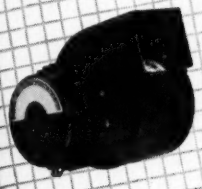
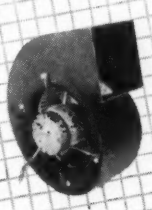
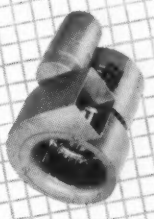
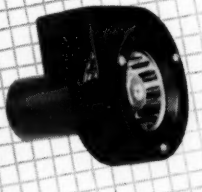
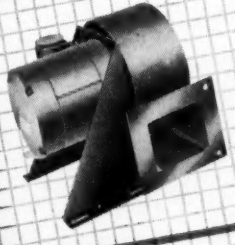
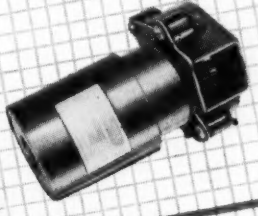
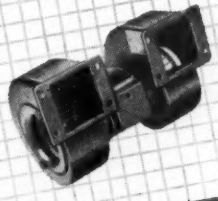
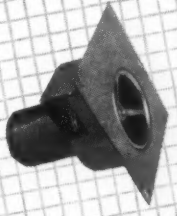
memo

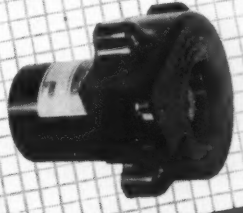
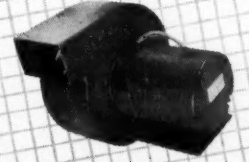
TO: Design Engineers

Here is a catalog which lists a complete line of quality blowers including all mechanical and electrical characteristics. Suggest you write for your own copy.

air-marine motors, inc.

centrifugal blowers

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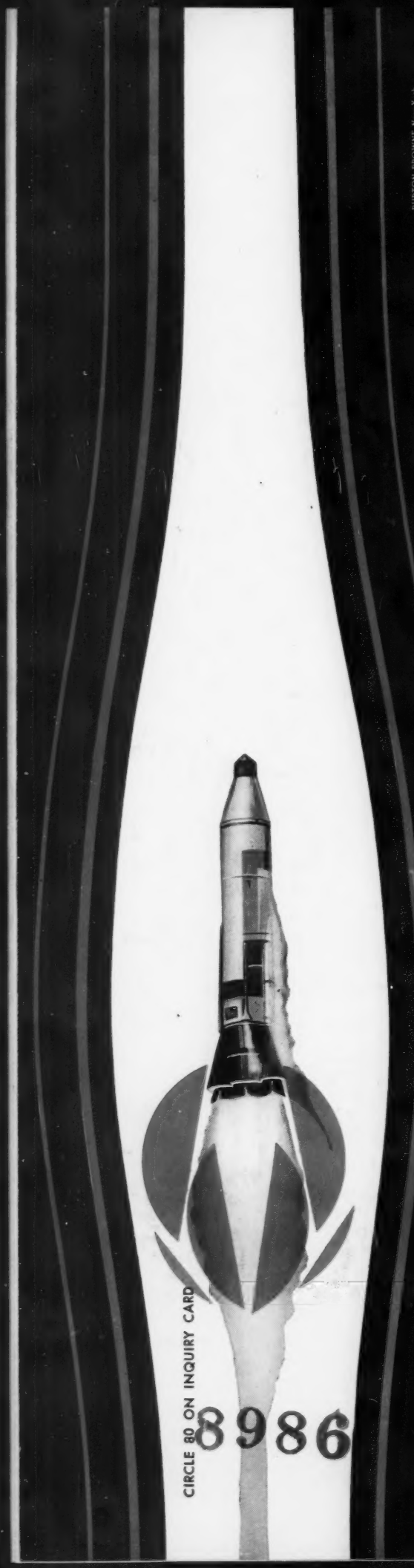

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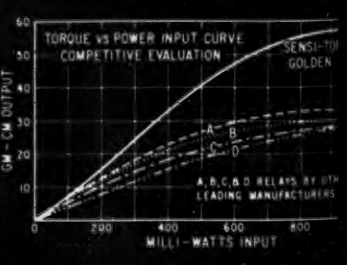

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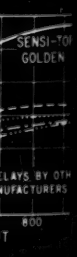
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